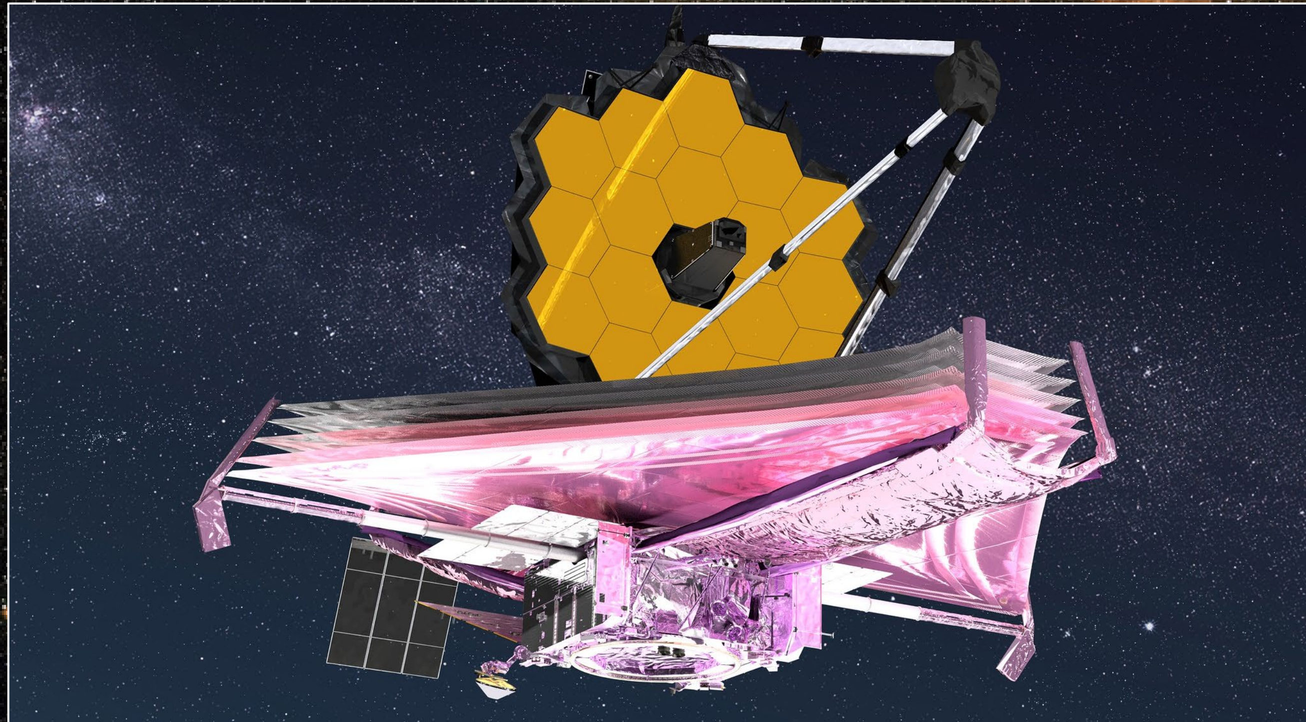


The James Webb Space Telescope

Mark Waldman
Science Instrument Commissioning Team
Senior Optical Test Engineer

JWST Introduction

- Webb will be the premier observatory of the next decade, serving thousands of astronomers worldwide.
- It will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System.

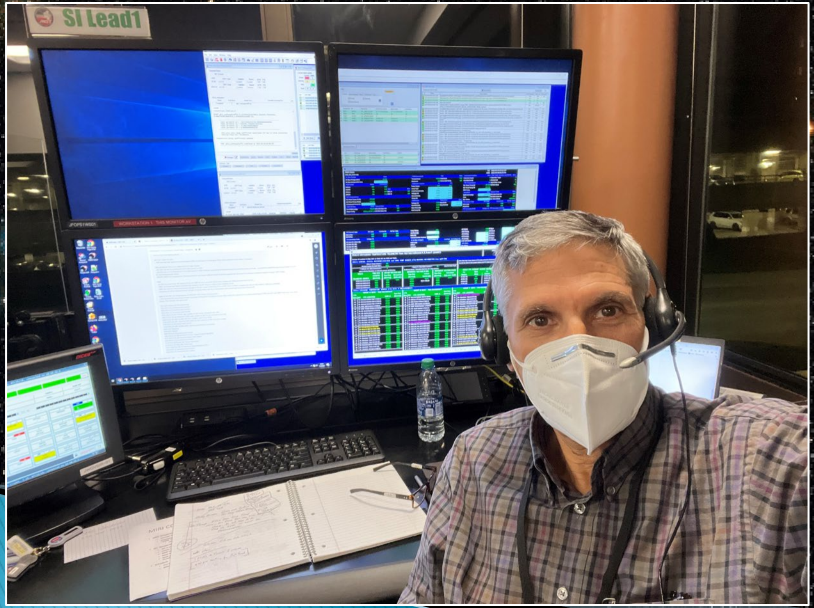
What is The James Webb Space Telescope?

- Largest Space Telescope Ever Built (6.5 meter (22 foot) Mirror)
- Unfolds (Deploys) In Space
- Operates at Colder Than 50K (-370F)
- Orbits L2 at 1 Million Miles Away From Earth
- Observes in Infra-red Spectrum to see up to 13 Billion Years into the Past
- International Collaboration: USA (NASA), Europe (ESA), Canada (CSA)
- Launched December 25, 2021
  - Ariane 5 Rocket launch from French Guiana

December 25
Launch!
“Go Webb Go”

Mark Waldman

- Optical Engineer (MS Optics ‘78, Univ. of Rochester)
- JWST Test Planning 2005->2017
  - Optical Systems Test run at Johnson Space Center (Houston) 2017
- JWST Commissioning Team (2018 -> current)

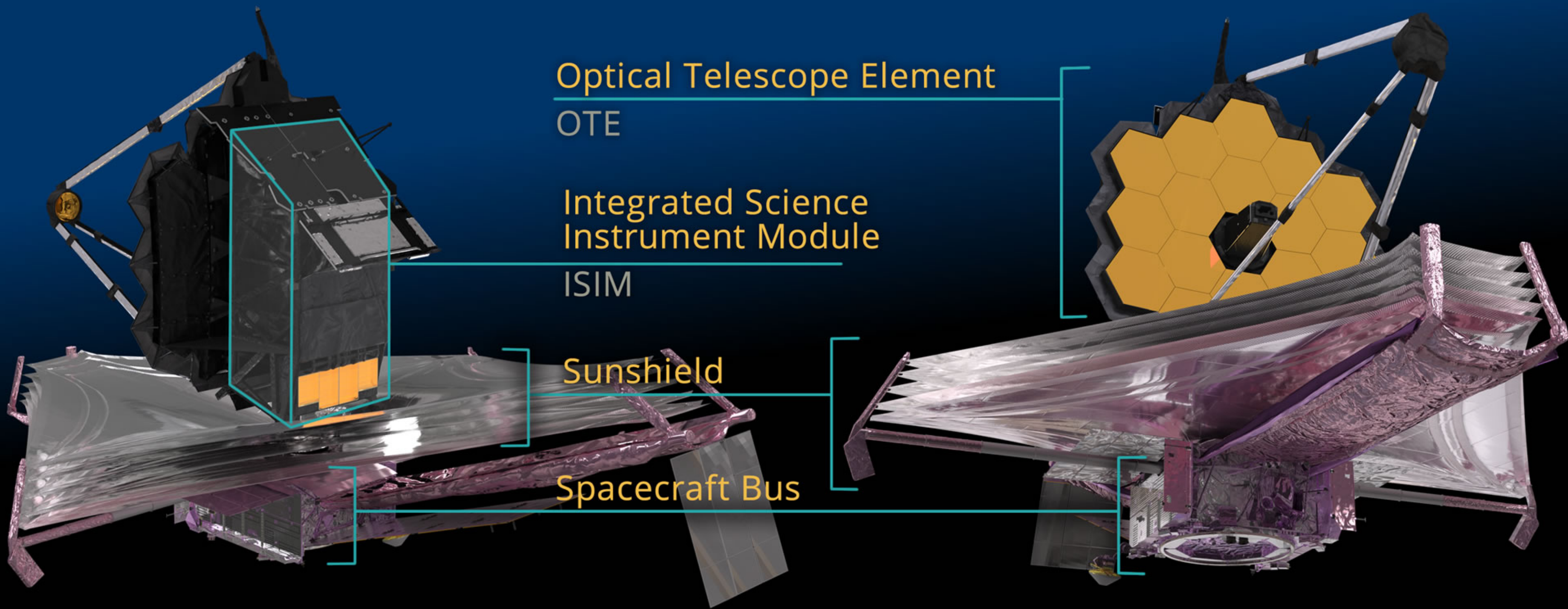


Topics

- What is the James Webb Space Telescope
- Science Themes
- How Does JWST Work?
- Commissioning
- Observing Plan – First Year
- Questions
- Closing

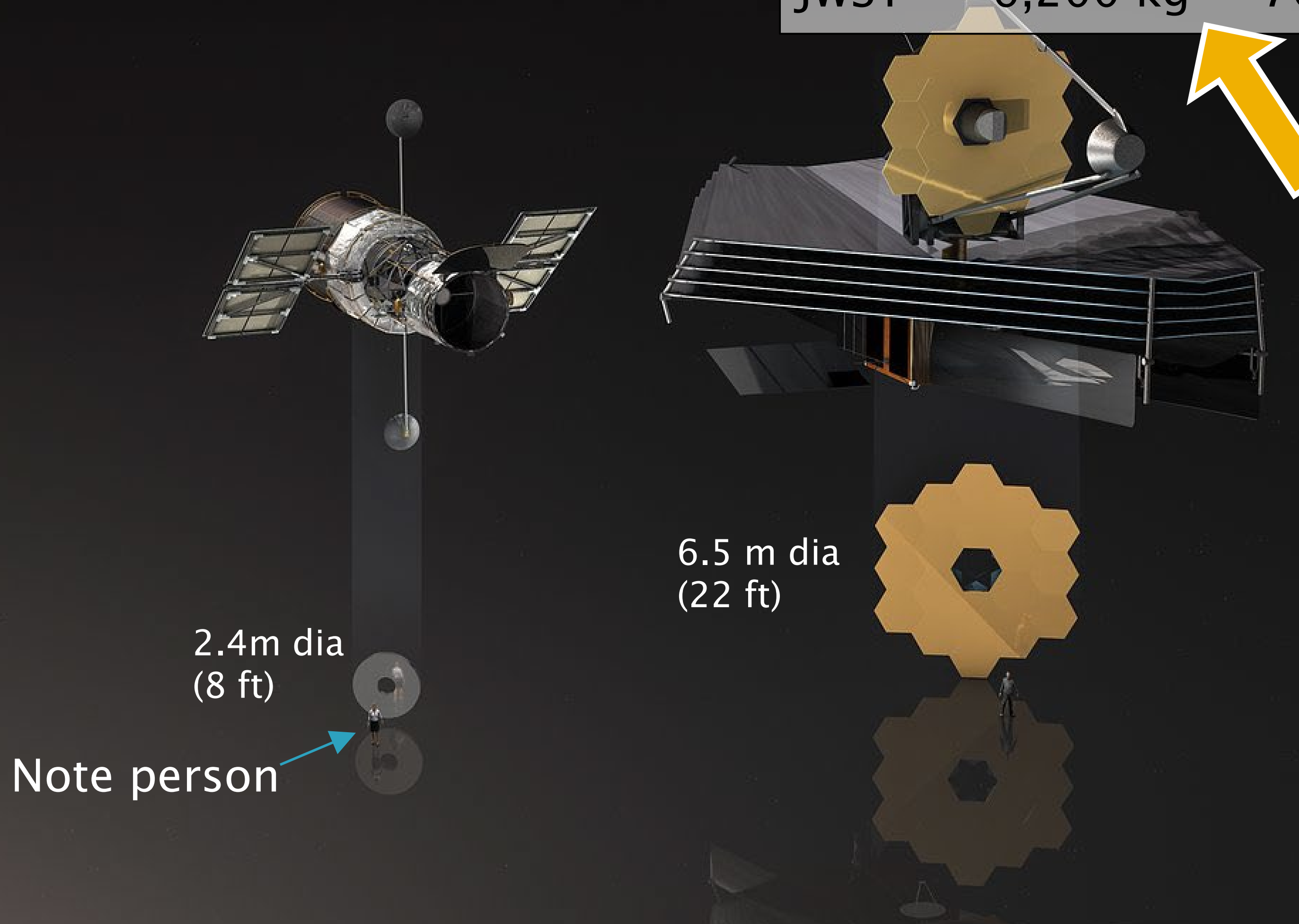
Full Scale Model

JWST Elements



Compare to Hubble

	Payload Mass	Primary Mirror Mass	Primary Mirror Area
Hubble	11,100 kg	828 kg	$4.5 m^2$
JWST	6,200 kg	705 kg	$25 m^2$

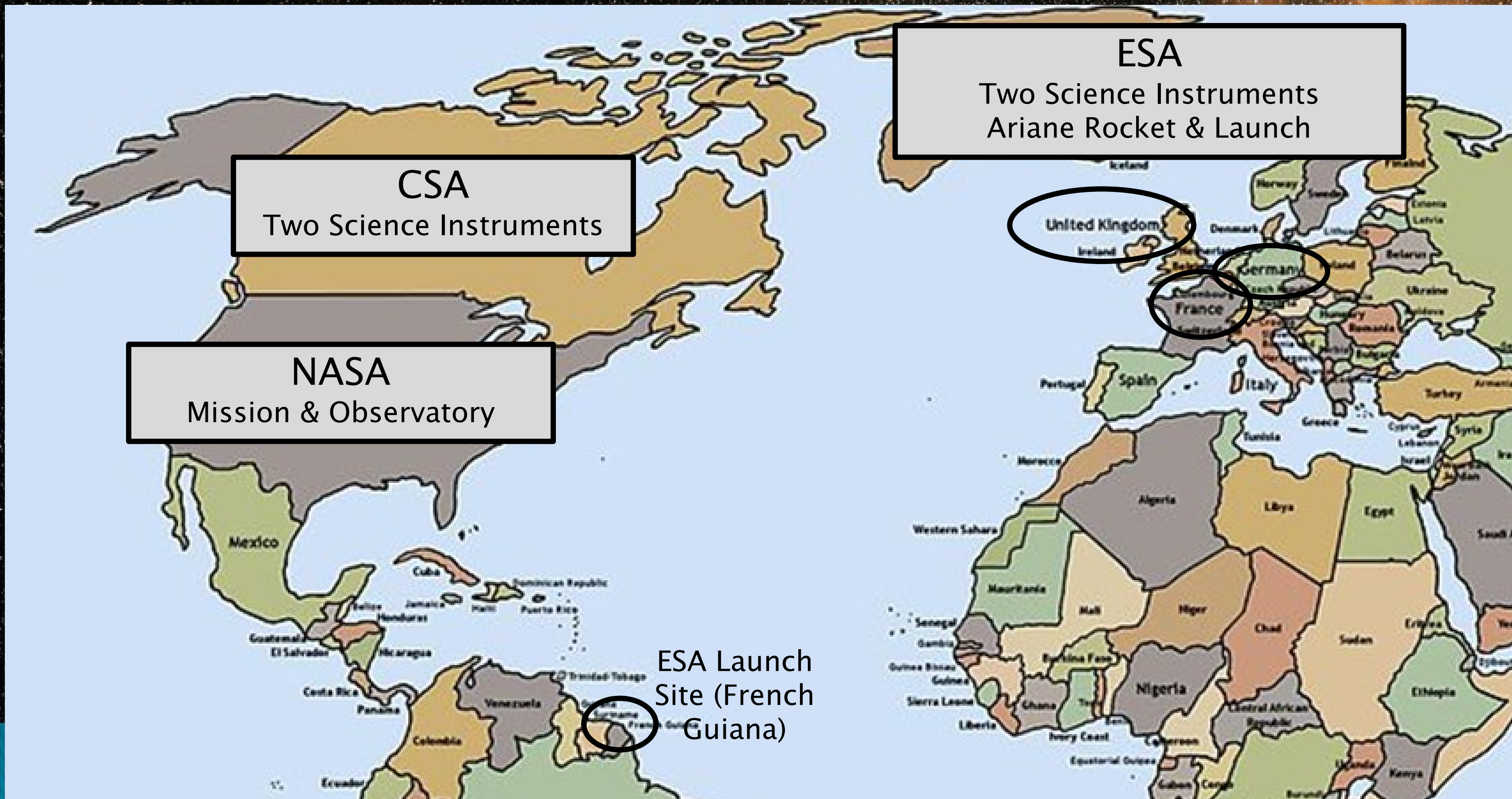


Less than 60% of Hubble Weight!

Over 5x More Area

JWST is So Large that it must be Folded to fit into the 4.6m (15’) Diameter Rocket Fairing.

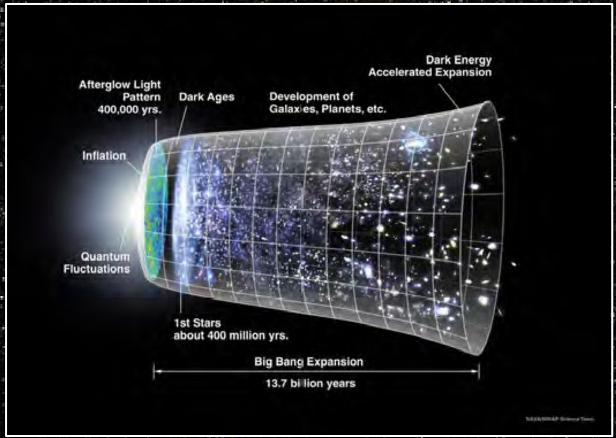
International Partners



JWST Science Themes

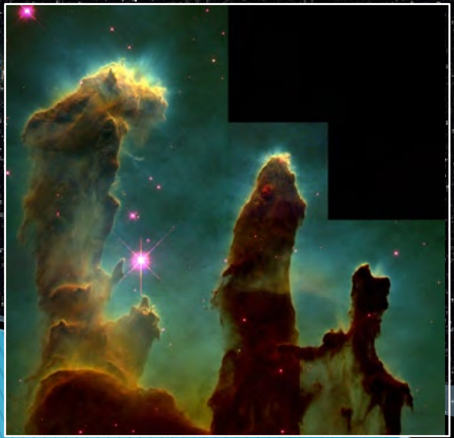
JWST: Four Science Themes

Early Universe

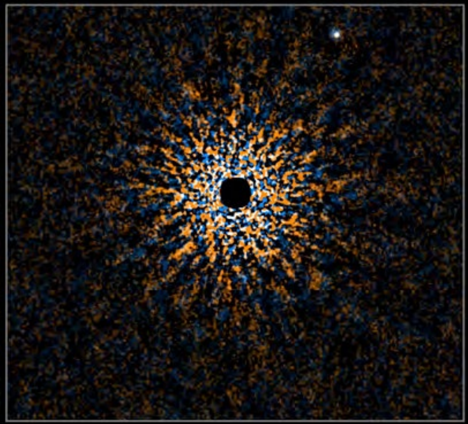


Galaxies Over Time

Star Lifecycle

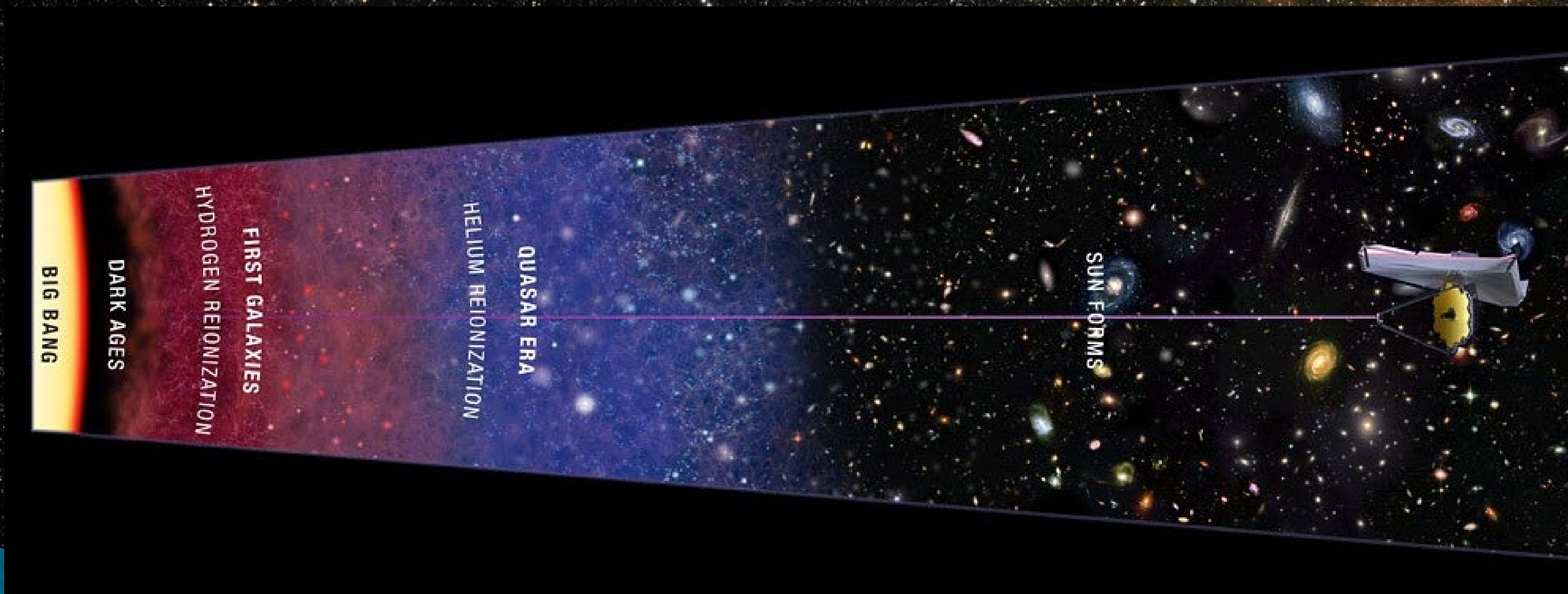


Other Worlds



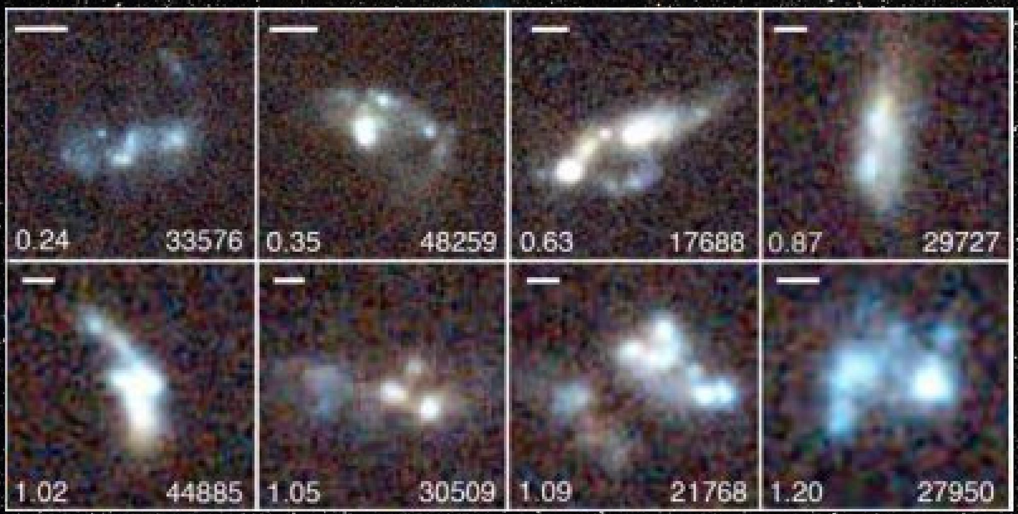
Early Universe

Peer back over 13.5 billion years to see the first stars and galaxies forming out of the darkness of the early universe.



Galaxies Over Time

Compare the faintest, earliest galaxies to today's grand spirals and ellipticals, helping us to understand how galaxies assemble over billions of years.



Very Distant (and old) Galaxies appear **Clumpy**

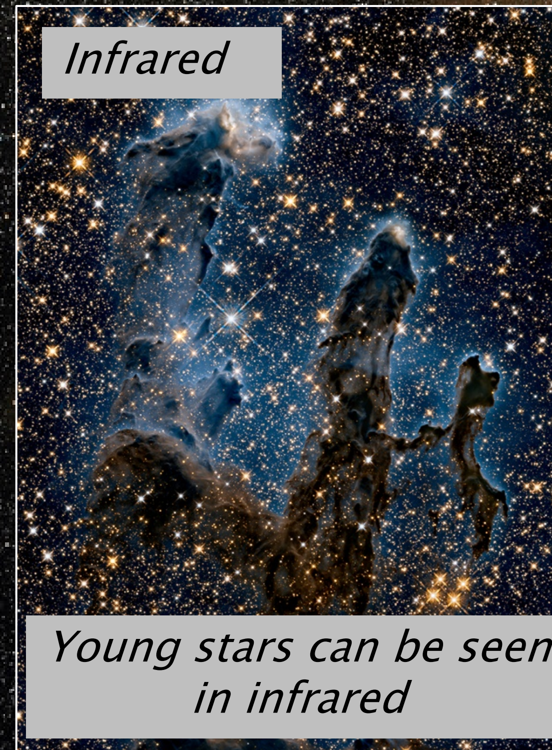
Closer (more modern) Galaxies appear more **organized and spiral**

Star Lifecycle

See through and into massive clouds of dust that are opaque to visible-light observatories like Hubble, where stars and planetary systems are being born.

Visible

Stellar nurseries are hidden by dust and gas



Infrared

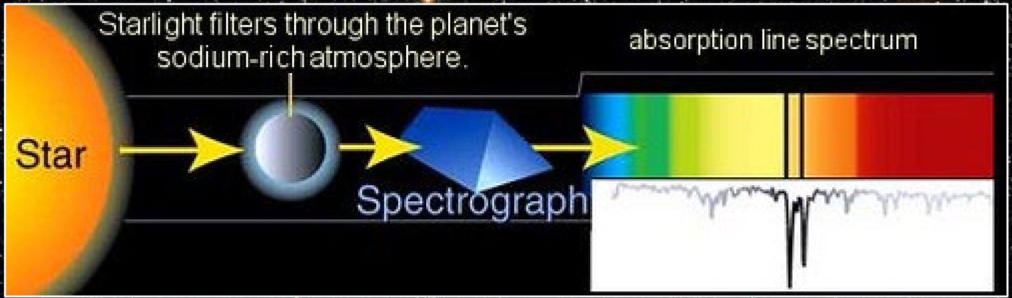
Young stars can be seen in infrared

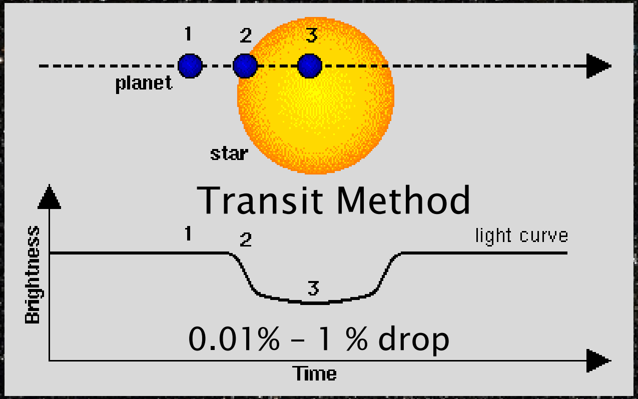
The Pillars of Creation in the Eagle Nebula (Hubble)

Other Worlds

Webb will tell us more about the atmospheres of extrasolar planets, and perhaps even find the building blocks of life elsewhere in the universe.

In addition to other planetary systems, Webb will also study objects within our own Solar System.



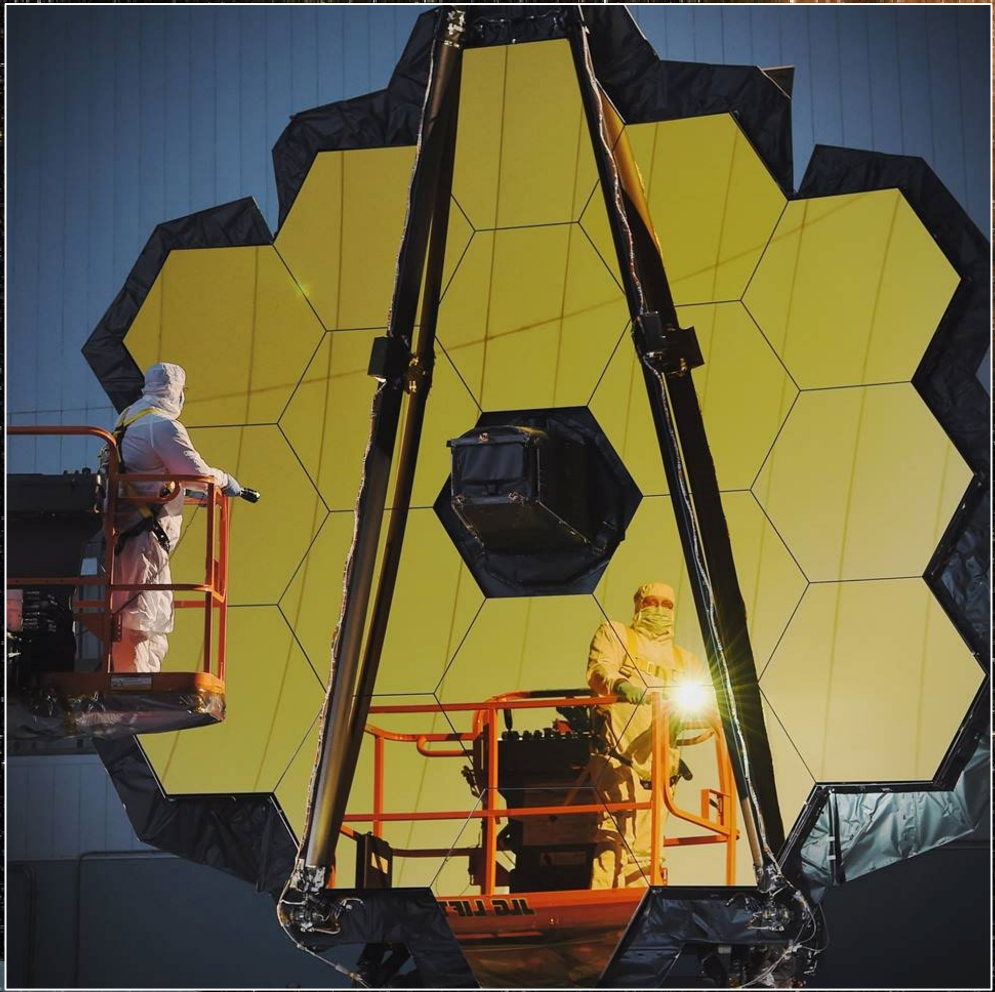


How Does JWST Do That?

Very large Primary Mirror
Infra Red
…Cold Telescope & Sensors
… … L2 Orbit
… … Sunshield

The JWST Primary Mirror

Big Mirror = See very dim things (collect lots of light)

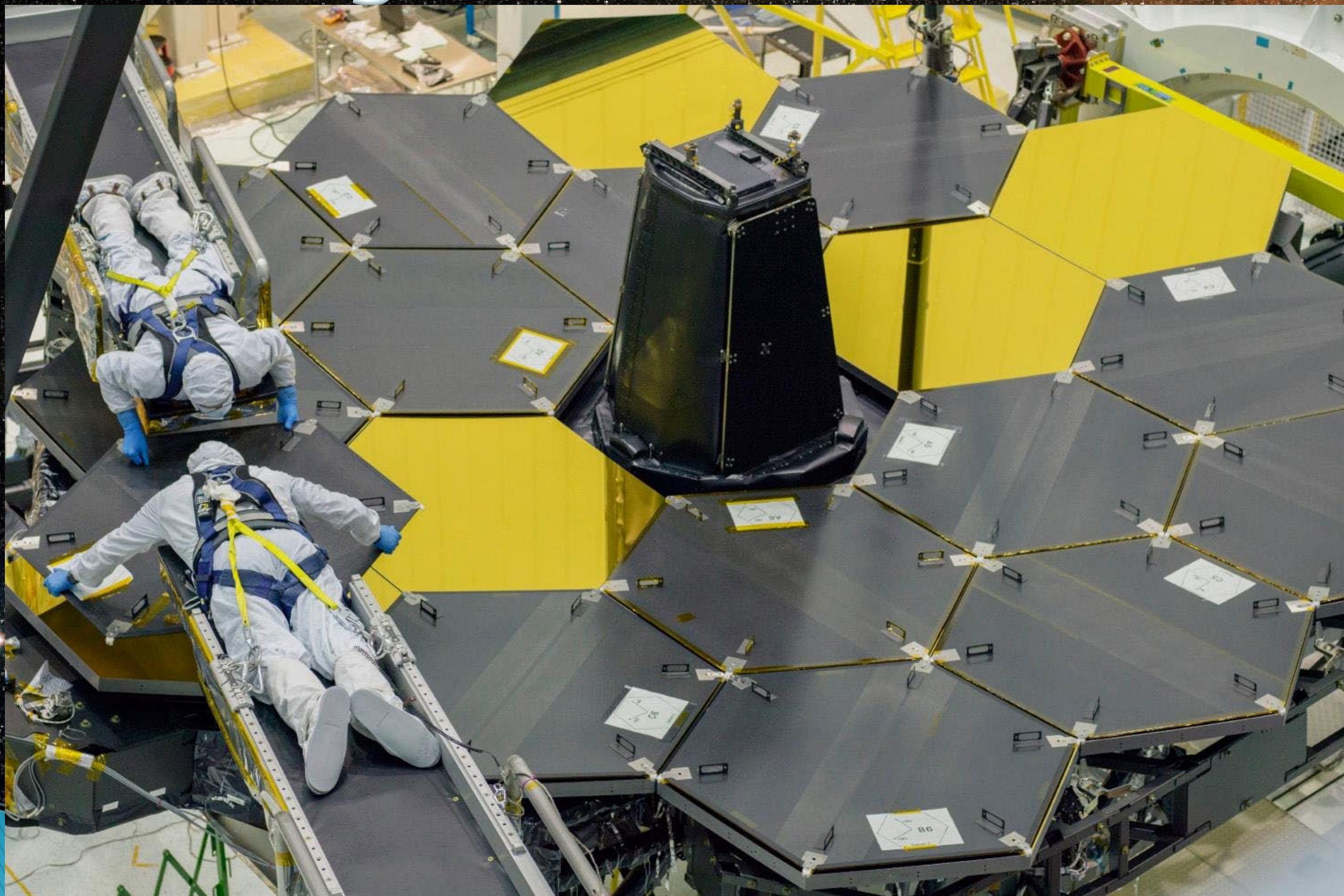


JWST Primary Mirror

- BIG – To See Dim Objects
- 18 Hexagonal Segments
  - 1.5m each (point to point)
- Beryllium / Light Weighted
- Coated with Gold
  - High IR Reflectance
- Deploys in Flight
  - Sides fold for launch
  - Segments deploy from launch lock and align in flight

One “Wing” Folded

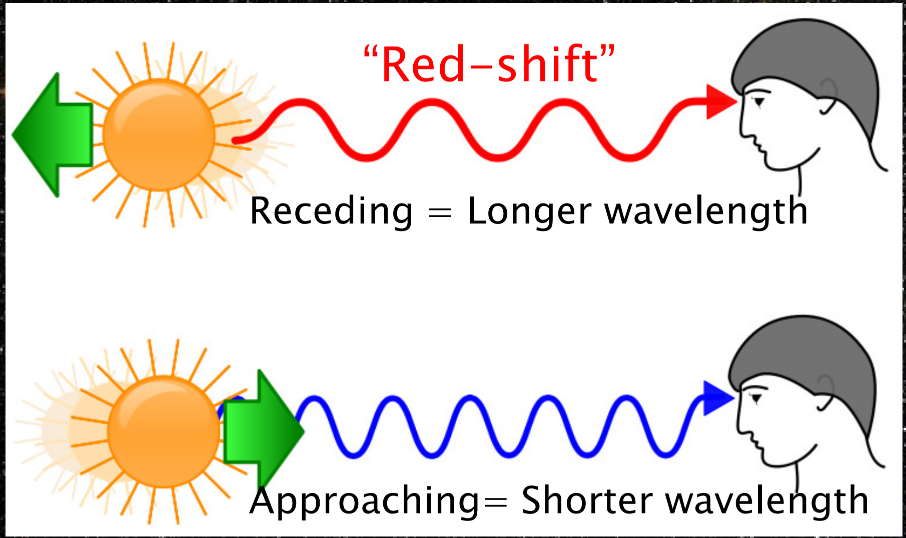
Removing the Covers



Why Infra-Red?

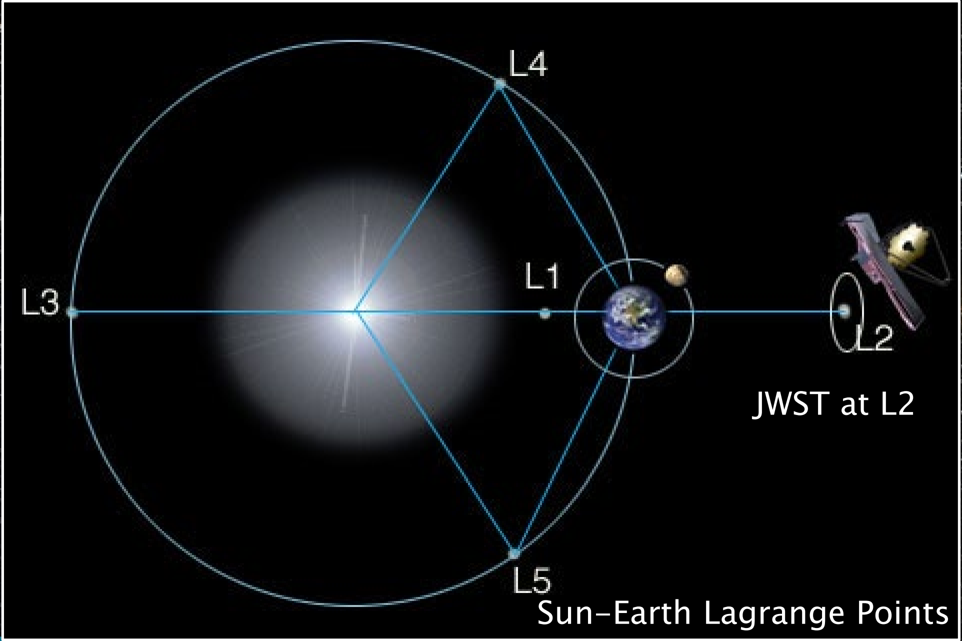
Infra-Red allows viewing of distant, oldest, and fastest-receding (red-shifted) stars

- Universe is expanding (stars appear to be receding)
  - Speed increases with distance
- Light from receding stars is 'red-shifted'
  - Color is shifted from visible to infra-red (longer wavelength)
  - The further away an object, the faster its recession and the more its light is redshifted from the visible into the infrared

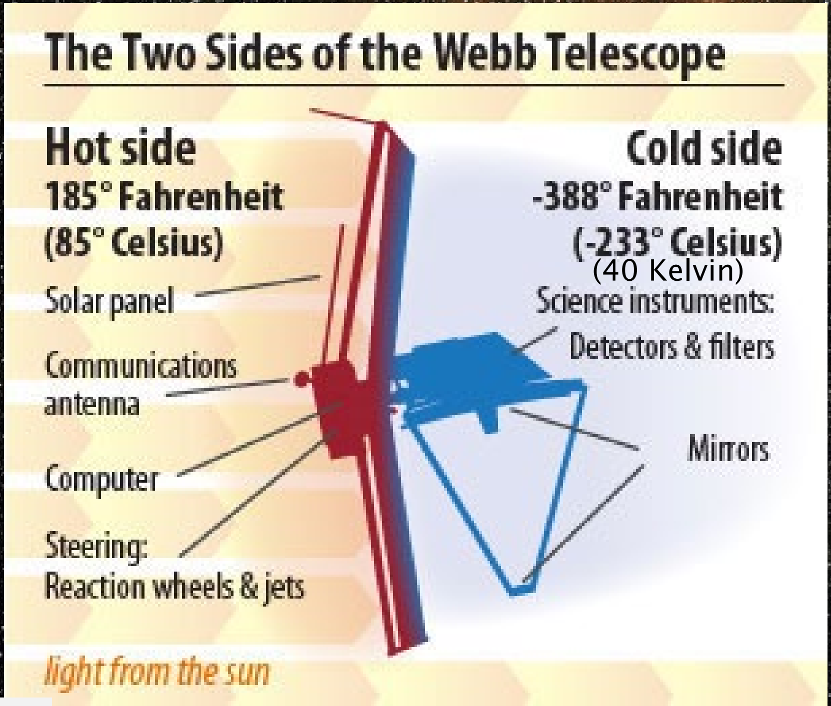


Cryogenic (Cold!) Telescope

- L2 Orbit and Sunshield keep JWST Cold

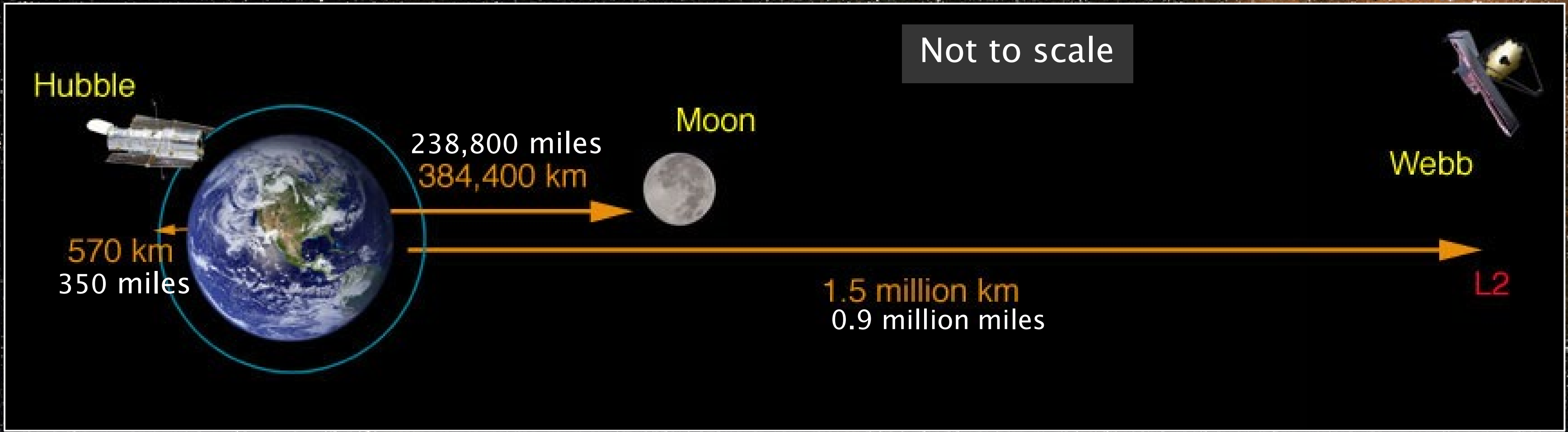


Sun–Earth Lagrange Points



Lagrange: Sun + Earth Gravity create Equilibrium points that orbit the Sun in phase with the Earth.

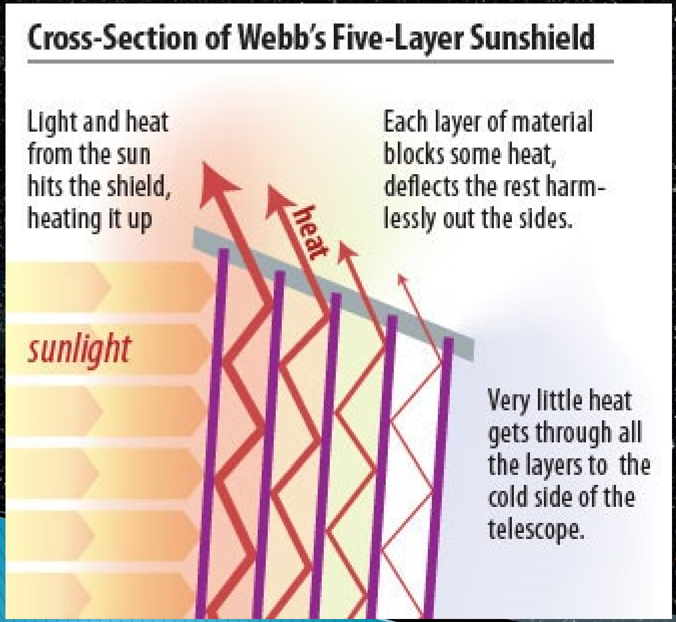
The L2 Location



JWST L2 Orbit (Video)

The Sunshield

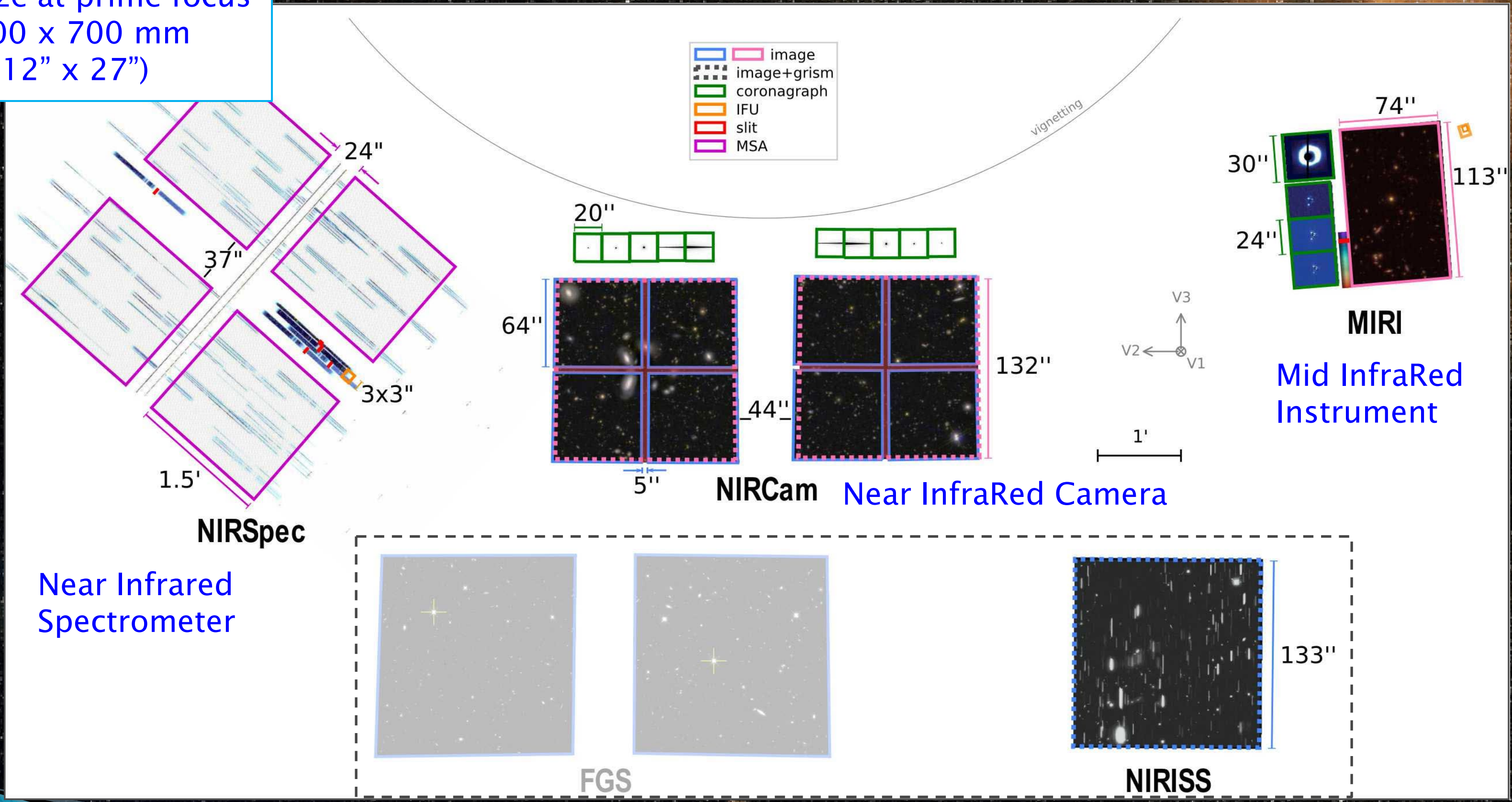
- 5 Kapton Layers (0.001 - 0.002 inch thick (25-50um)
- 47' x 70' (approx tennis-court size)
- Folds for launch; deploys in space



JWST Has 5 Instruments (Cameras)

The JWST instruments view different portions of the JWST focal plane

Field size at prime focus
~300 x 700 mm
(12” x 27”)



Fine Guidance Sensor

Near InfraRed Imager and Slitless Spectrograph

What Has Happened Since Launch?

What's Coming Up?

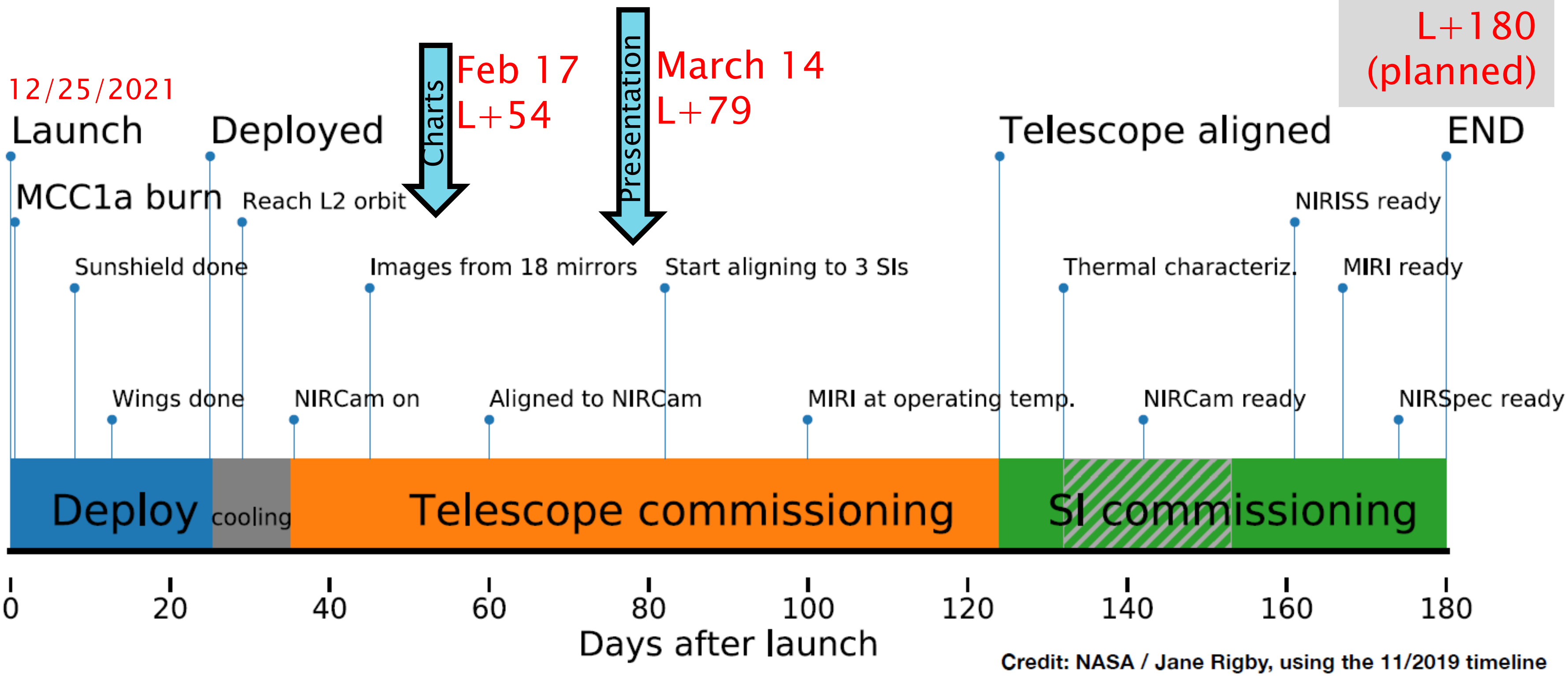
Commissioning Activities Since Launch

- Deployments
- Telescope Commissioning

What’s Coming Up?

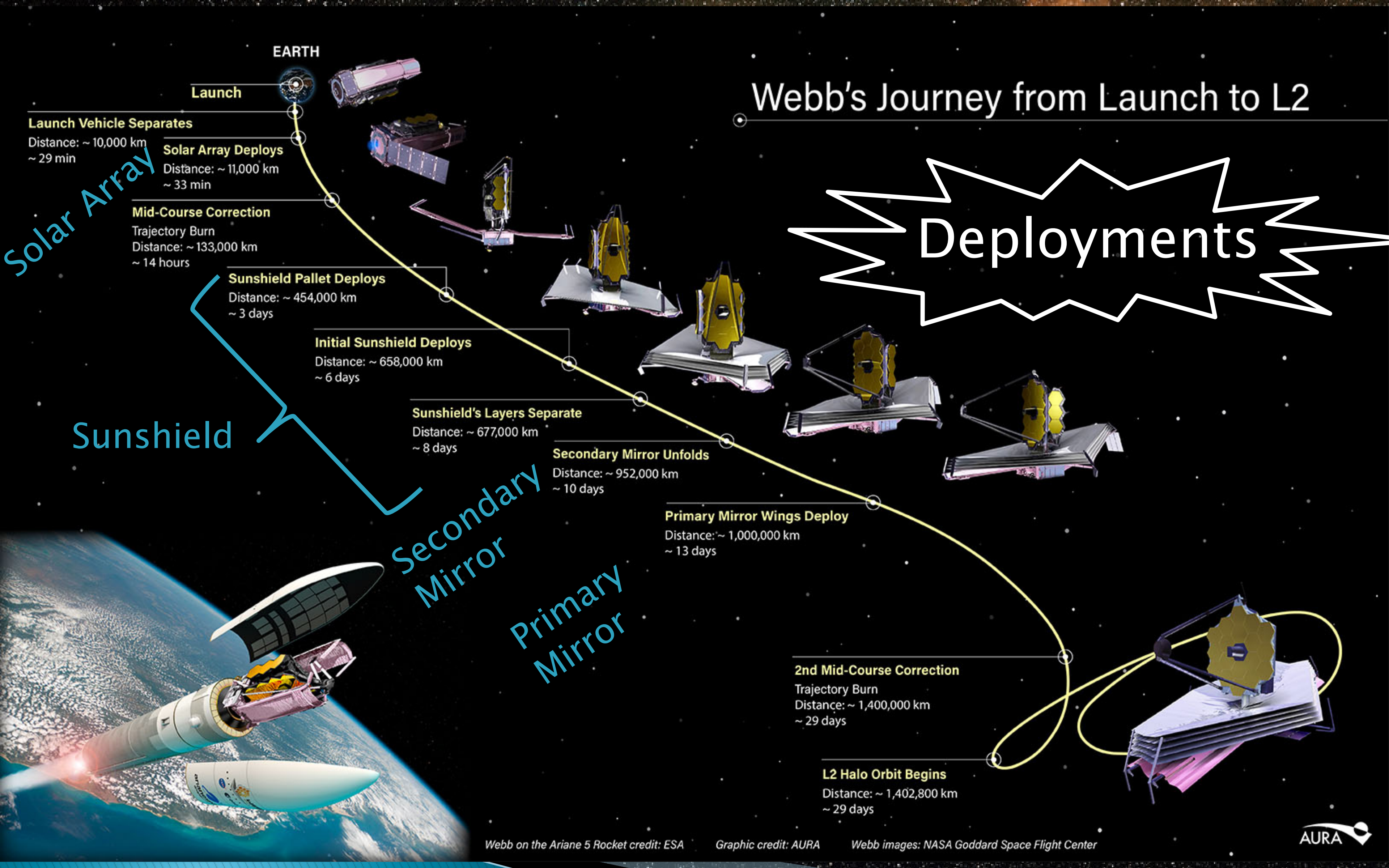
- Remaining Commissioning
- Science (Astronomy)

A high-level overview of JWST commissioning



https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/D4078F6BF6528CCFA867A4016CAF804389D01D8CA777

JWST Status Update for the NAS Committee on Astronomy and Astrophysics
Jane Rigby
31 March 2020


Webb's Journey from Launch to L2
Deployments
EARTH
Launch
Launch Vehicle Separates
Distance: ~ 10,000 km
~ 29 min
Solar Array Deploys
Distance: ~ 11,000 km
~ 33 min
Solar Array
Mid-Course Correction
Trajectory Burn
Distance: ~ 133,000 km
~ 14 hours
Sunshield Pallet Deploys
Distance: ~ 454,000 km
~ 3 days
Initial Sunshield Deploys
Distance: ~ 658,000 km
~ 6 days
Sunshield
Sunshield's Layers Separate
Distance: ~ 677,000 km
~ 8 days
Secondary Mirror Unfolds
Distance: ~ 952,000 km
~ 10 days
Secondary Mirror
Primary Mirror Wings Deploy
Distance: ~ 1,000,000 km
~ 13 days
Primary Mirror
2nd Mid-Course Correction
Trajectory Burn
Distance: ~ 1,400,000 km
~ 29 days
L2 Halo Orbit Begins
Distance: ~ 1,402,800 km
~ 29 days
Webb on the Ariane 5 Rocket credit: ESA
Graphic credit: AURA
Webb images: NASA Goddard Space Flight Center
AURA

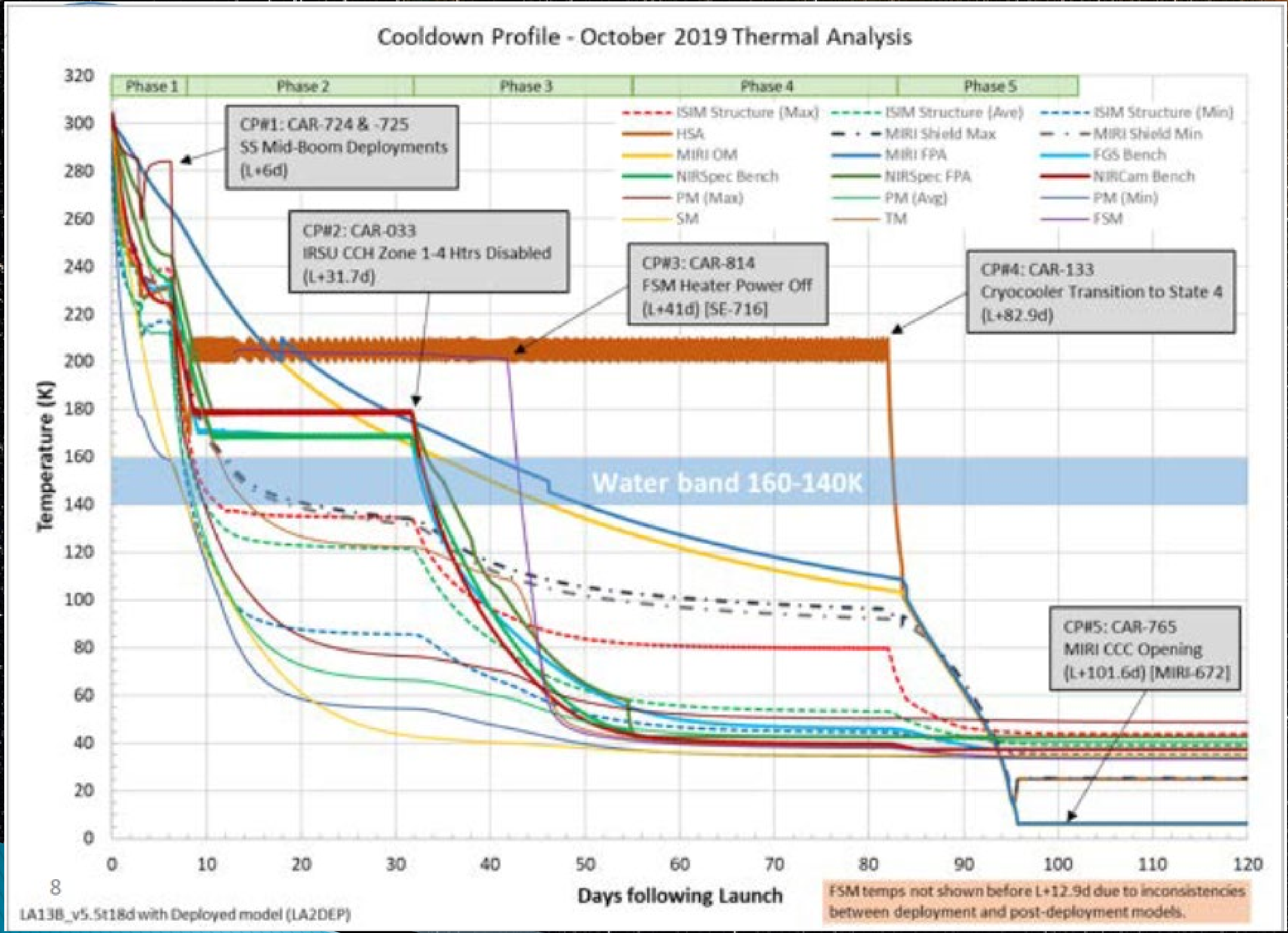
Deployment Plan Video

JWST Actual Final View & Solar Array Deployment

Secondary Mirror Deployment (Clip)

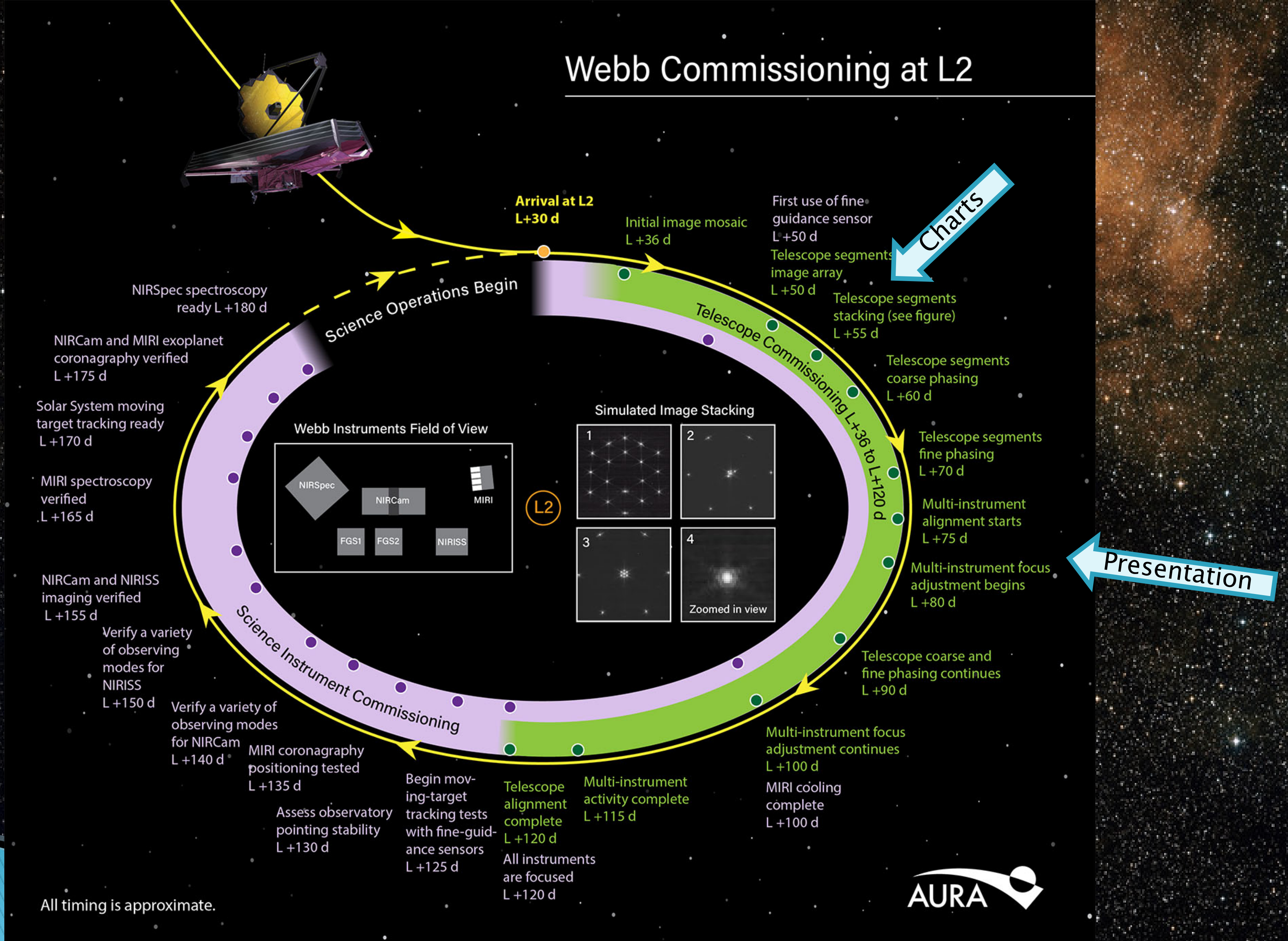
Primary Mirror Wing Deployment (Clip)

Observatory Cooldown Profile



Cooldown is CAREFULLY managed (with heaters) to avoid contamination and strain

https://www.stsci.edu/files/live/sites/www/files/home/jwst/science-planning/user-committees/jwst-users-committee/_documents/jstuc-1220-jwst-commissioning-friedman.pdf



Webb Commissioning at L2
Arrival at L2
L+30 d
Initial image mosaic
L +36 d
First use of fine guidance sensor
L +50 d
Telescope segments image array
L +50 d
Telescope segments stacking (see figure)
L +55 d
Telescope segments coarse phasing
L +60 d
Telescope segments fine phasing
L +70 d
Multi-instrument alignment starts
L +75 d
Multi-instrument focus adjustment begins
L +80 d
Telescope coarse and fine phasing continues
L +90 d
Multi-instrument focus adjustment continues
L +100 d
MIRI cooling complete
L +100 d
Multi-instrument activity complete
L +115 d
Telescope alignment complete
L +120 d
All instruments are focused
L +120 d
Begin moving-target tracking tests with fine-guidance sensors
L +125 d
Assess observatory pointing stability
L +130 d
MIRI coronagraphy positioning tested
L +135 d
Verify a variety of observing modes for NIRCam
L +140 d
Verify a variety of observing modes for NIRISS
L +150 d
NIRCam and NIRISS imaging verified
L +155 d
MIRI spectroscopy verified
L +165 d
Solar System moving target tracking ready
L +170 d
NIRCam and MIRI exoplanet coronagraphy verified
L +175 d
NIRSpec spectroscopy ready L +180 d
Science Operations Begin
Telescope Commissioning L+36 to L+120 d
Science Instrument Commissioning
Webb Instruments Field of View
NIRSpec
NIRCam
MIRI
FGS1
FGS2
NIRISS
L2
Simulated Image Stacking
1
2
3
4
Zoomed in view
All timing is approximate.
AURA
Charts
Presentation

PMSA Alignment via Wavefront Sensing & Control (WFSC)

WFSC uses images of stars to measure state of alignment

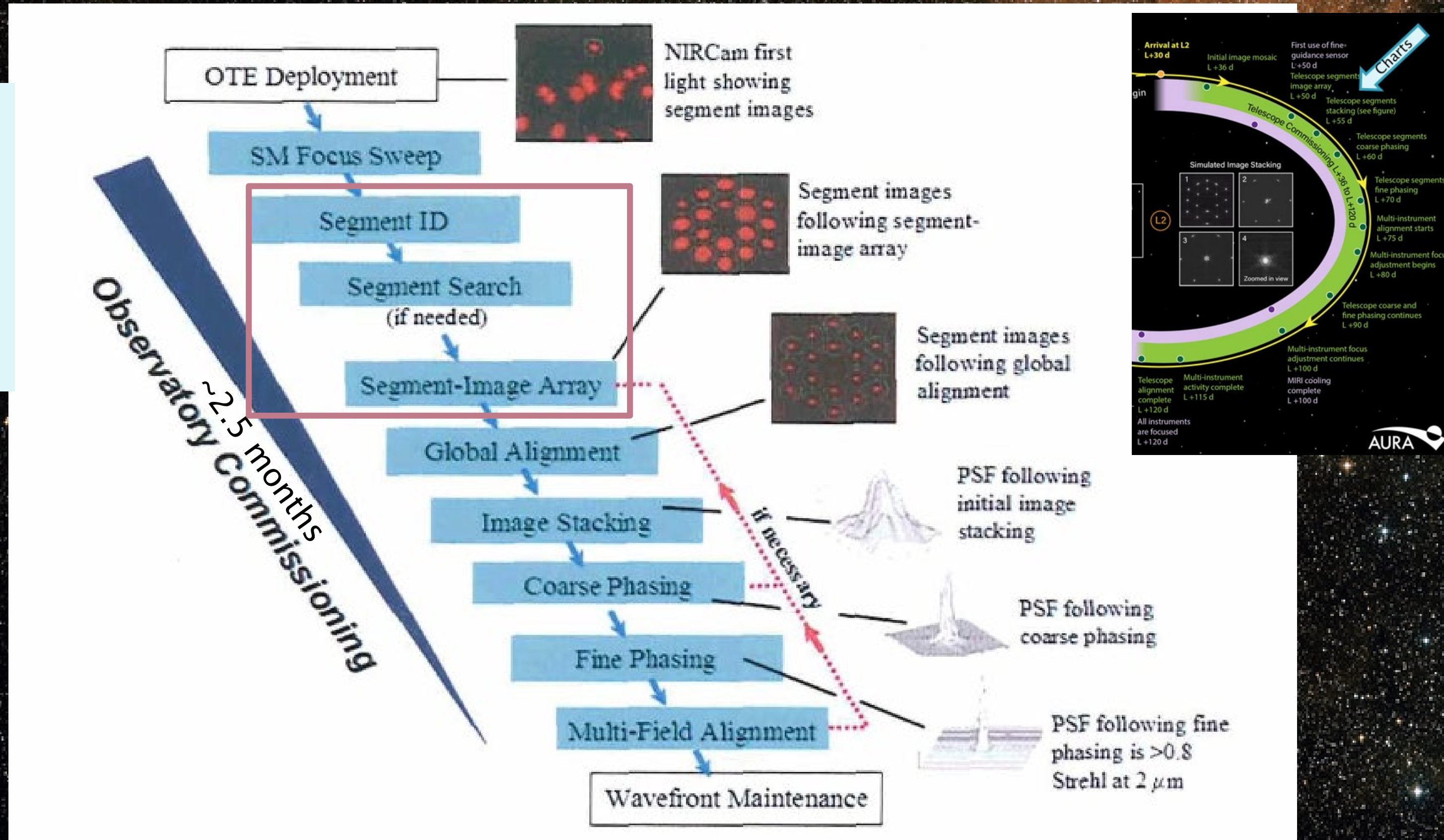


Fig. 11. Block Diagram of Commissioning Steps

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008397.pdf

First Image

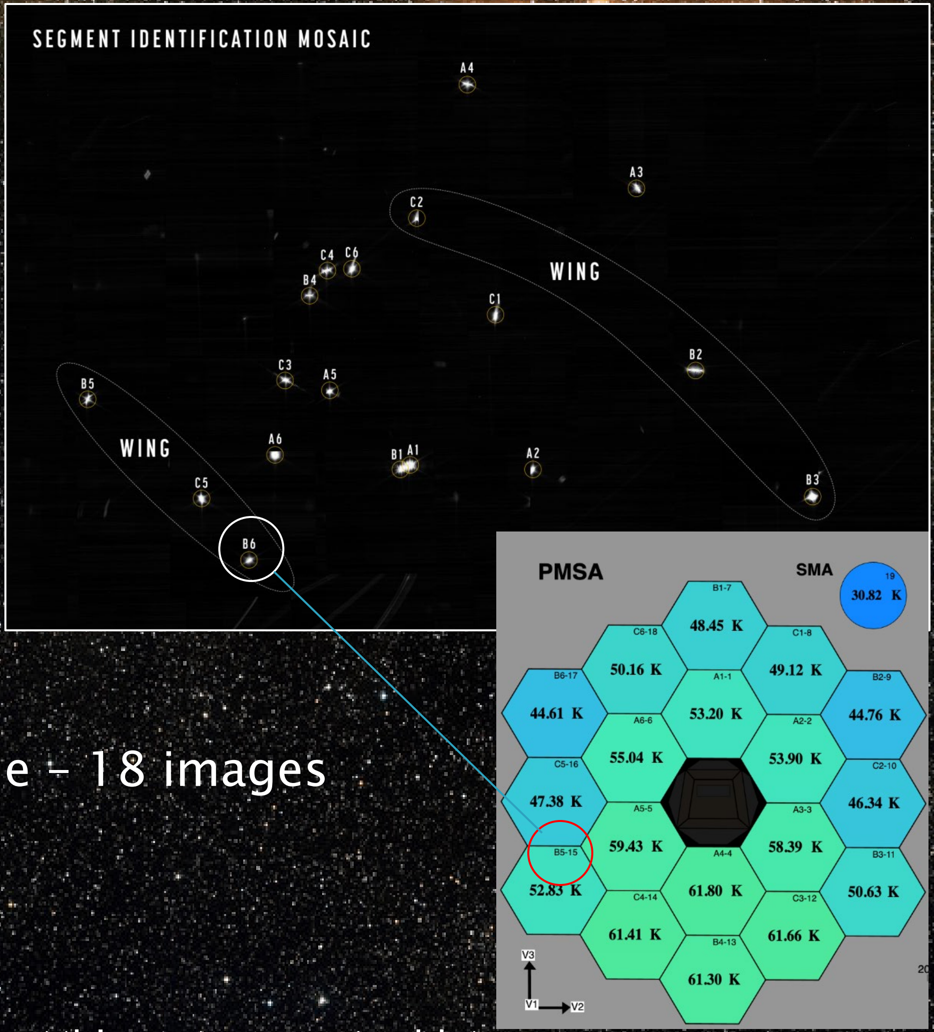


Image of a single star

Each segment produces a separate image – 18 images

https://blogs.nasa.gov/webb/

Webb Selfie

2/11/2022

This "selfie" was created using a specialized pupil imaging lens inside of the NIRCam instrument that was designed to take images of the primary mirror segments instead of images of space.

This configuration is not used during scientific operations and is used strictly for engineering and alignment purposes.

In this case, the bright segment was pointed at a bright star, while the others aren't currently in the same alignment.

This image gave an early indication of the primary mirror alignment to the instrument. Credit: NASA

https://blogs.nasa.gov/webb/

What Will Webb Look At?

First Year "Cycle 1" Observing Plan

Early Release Observations (ERO) 500 hrs	At End of Commissioning Public Appeal ("WOW") and Demonstration
Guaranteed Time Observations (GTO) 4,000 hrs	Awarded to scientists who helped develop the key hardware and software
General Observer (GO) 6,000 hrs	Awarded based on Proposal Process (1172 received, 266 selected from 41 countries)

Timeline is Oversubscribed (1 year = 8,760 hrs)

Scheduling JWST is not trivial. 39% of the sky is observable at any time; 100% over the course of a year.

Many Astronomy Topics

Early Release

- Galaxies and Intergalactic Medium
- Massive Black Holes and Their Host Galaxies
- Planets and Planet Formation
- Solar System
- Stellar Physics
- Stellar Populations

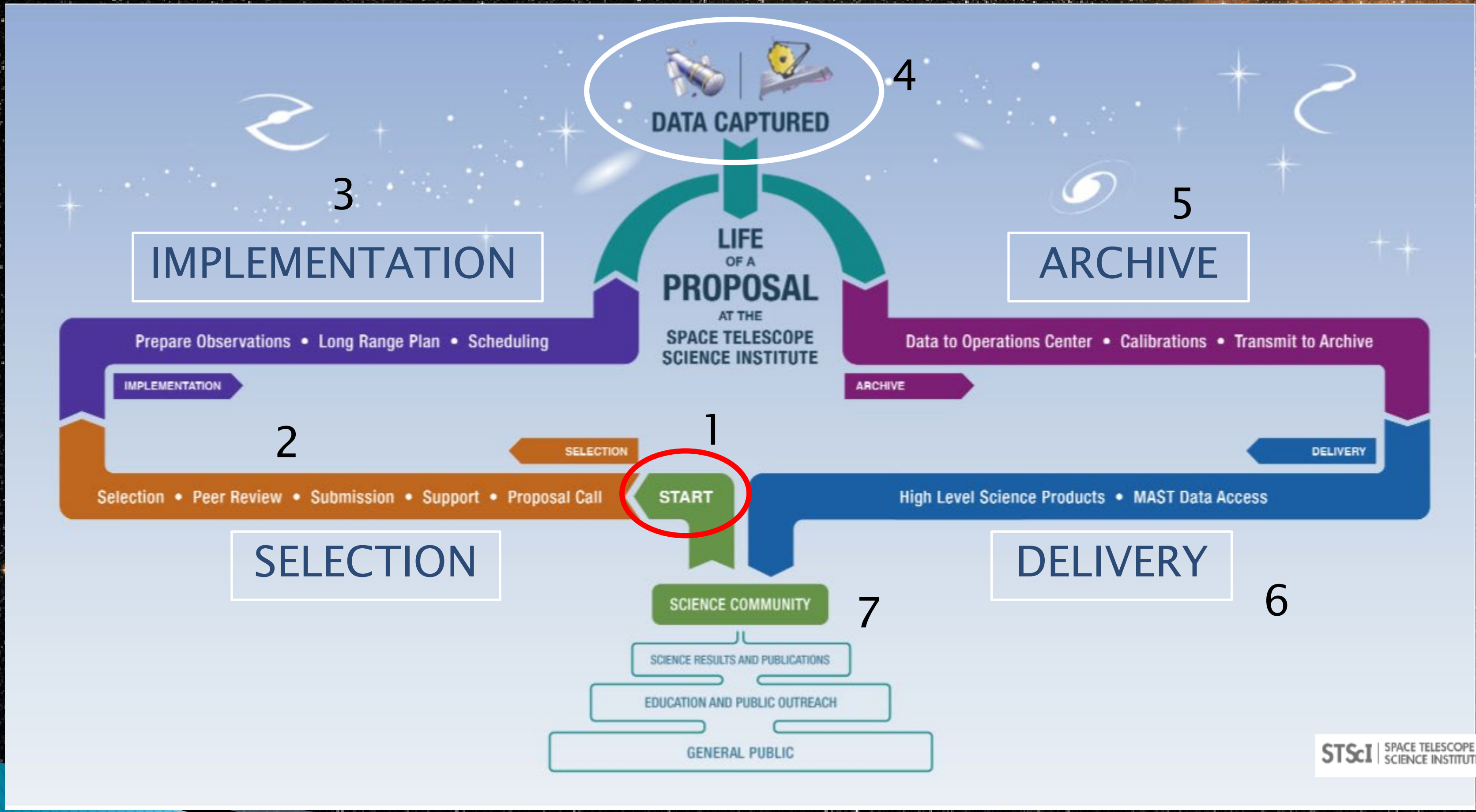
Guaranteed Time

- Brown Dwarfs
- Clusters of Galaxies
- Debris Disks and Photodissociation Regions
- Deep Fields
- Extra-solar Planets
- High-redshift Quasars and Galaxy Assembly
- Protostars, Protostellar Disks, and Young Stellar Objects
- Solar System
- Star Clusters, Star Formation Regions, Planetary Nebulae, and Galactic Transients
- Targeted Galaxies

General Observer

- Exoplanets
- Galaxies
- Intergalactic Medium and the Circumgalactic Medium
- Large Scale of the Universe
- Solar System Astronomy
- Stellar Physics and Stellar Types
- Stellar Populations and the Interstellar Medium
- Supermassive Black Holes and Active Galactic Nucleus

Getting Time on the Telescope



https://jwst-docs.stsci.edu/files/107249741/109184254/6/1614306635453/JWSTCycle-PanelSupport.pdf

Resources

https://jwst.nasa.gov
https://blogs.nasa.gov/webb

Email me: mark@markwaldman.com

Where Is Webb?

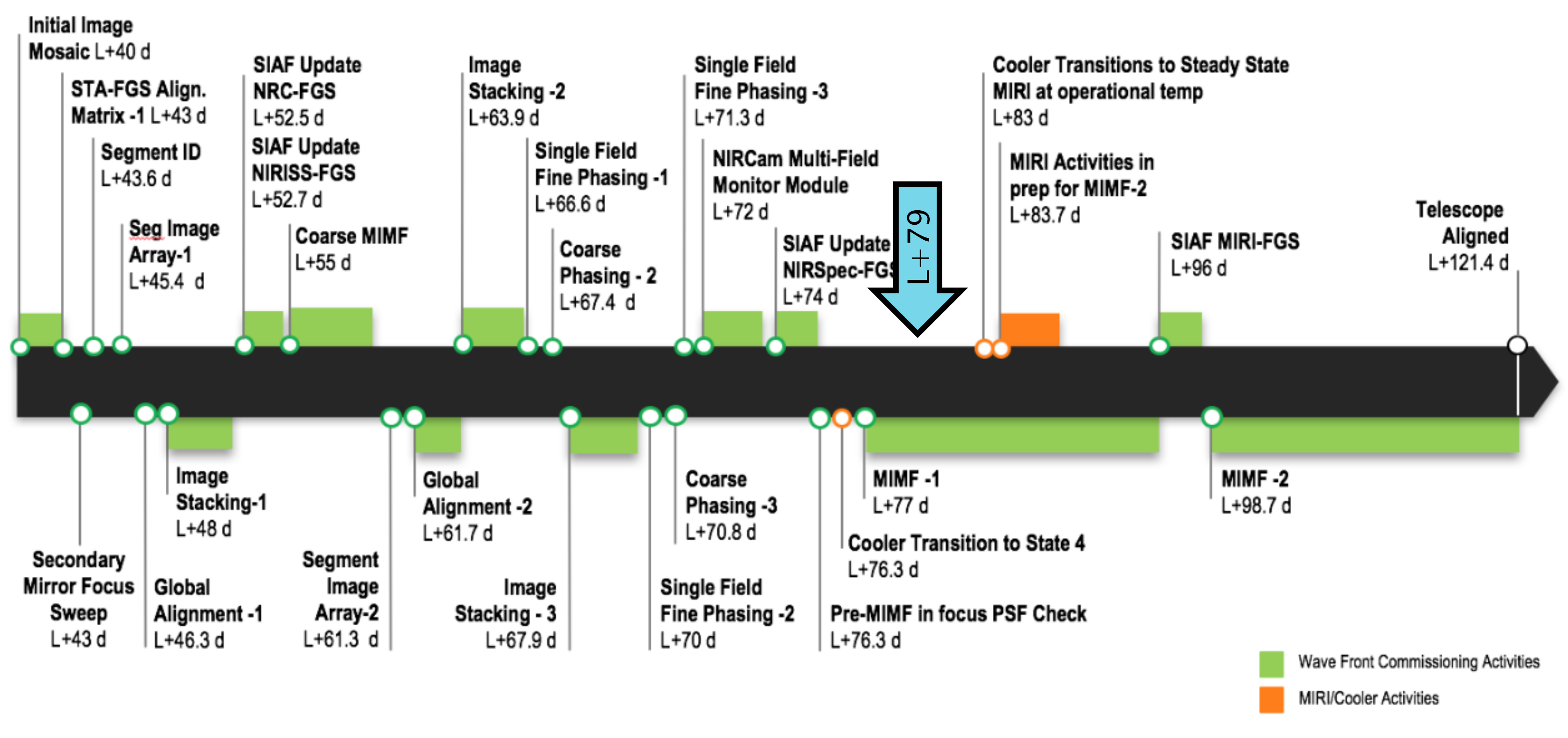
The James Webb Space Telescope (at L2) Truly Out Of This World

The James Webb Space Telescope

Mark Waldman 2022

Backup Slides

Telescope Commissioning (Mirror Alignments)



https://www.stsci.edu/files/live/sites/www/files/home/jwst/news-events/events/2017/_documents/jstuc-0917-commissioning-friedman.pdf

Telescope Alignment Simulation

PMSA Alignment via Wavefront Sensing & Control (WFSC)

WFSC uses images of stars to measure state of alignment

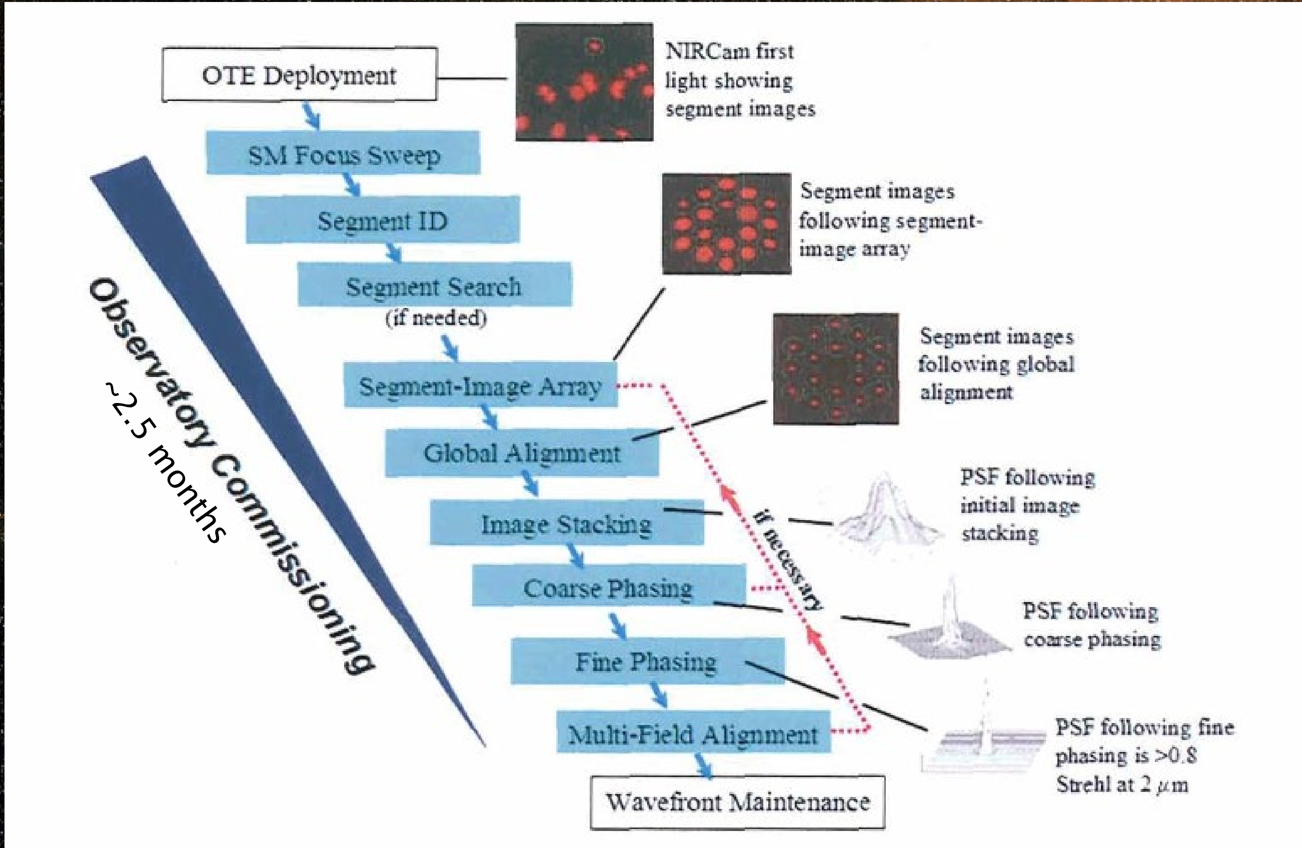


Fig. 11. Block Diagram of Commissioning Steps

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008397.pdf

Simulated "First Light" Image

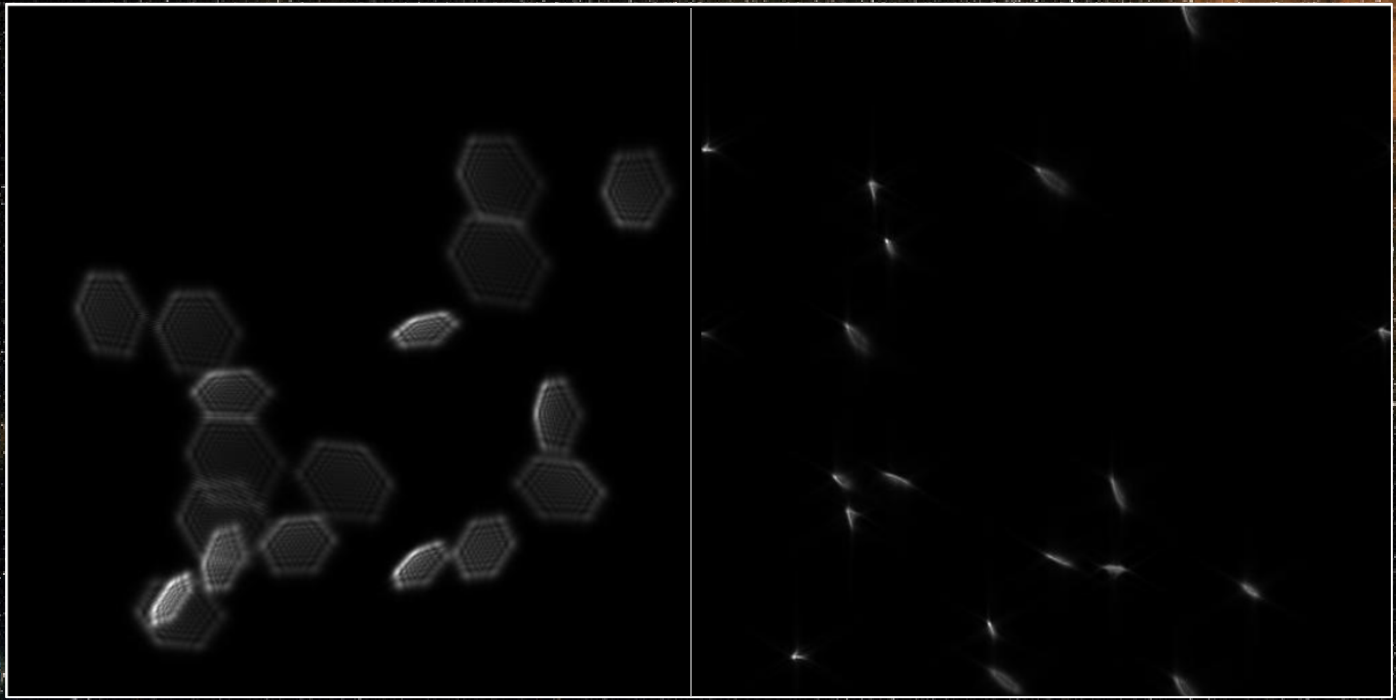


Figure 1. Example of first light image with 3 mm SM despace error (left) and at the nominal focus position (right). The SM needs to be close to the nominal focus position in order to proceed to the segment ID stage of the commissioning process.

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.823.4123&rep=rep1&type=pdf

Optical, Infrared, and Millimeter Space Telescopes, edited by John C. Mather, Proceedings of SPIE Vol. 5487 (SPIE, Bellingham, WA, 2004)

Simulated Segment ID Images

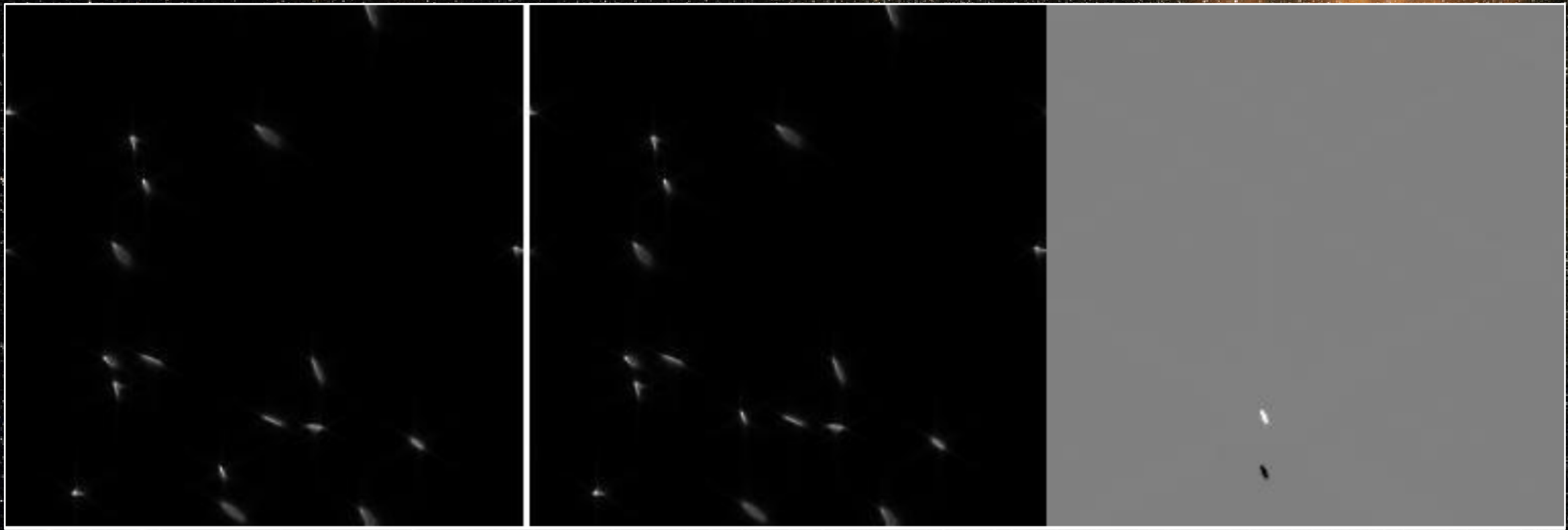


Figure 2. Images before (left) and after (middle) tilting a segment by about 5 arcseconds. Taking the difference between the two images (right) gives a clear indication of the spot associated with the tilted segment.

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.823.4123&rep=rep1&type=pdf

Optical, Infrared, and Millimeter Space Telescopes, edited by John C. Mather, Proceedings of SPIE Vol. 5487 (SPIE, Bellingham, WA, 2004)

Simulated Coarse Alignment Images

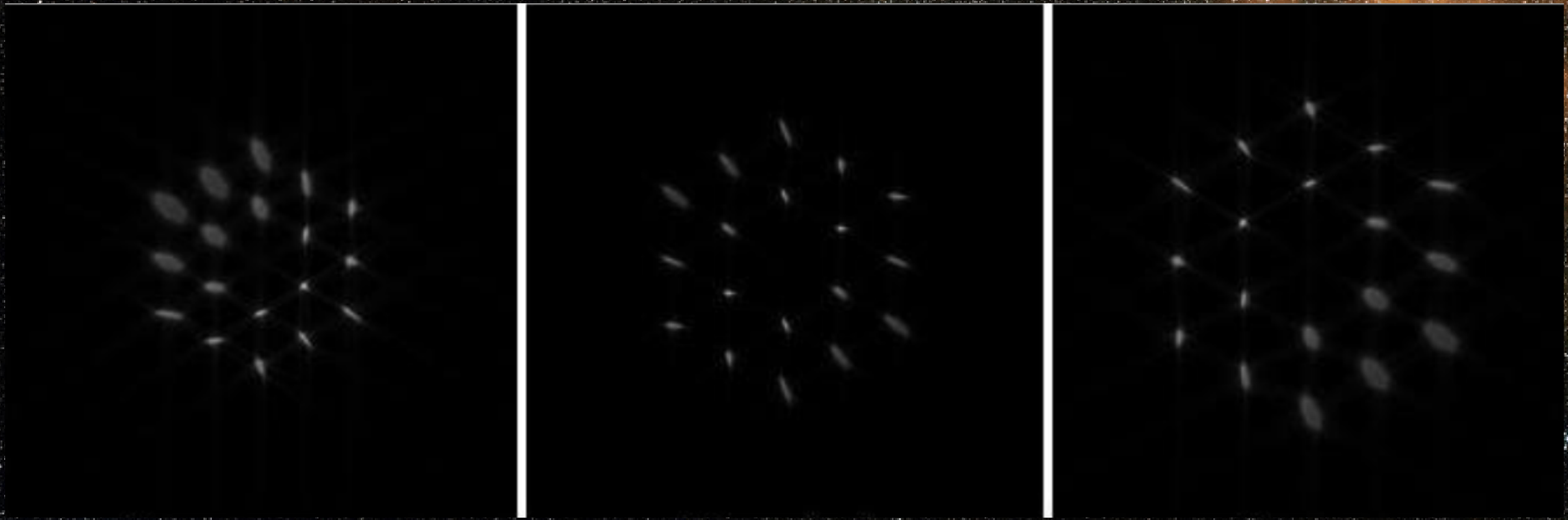


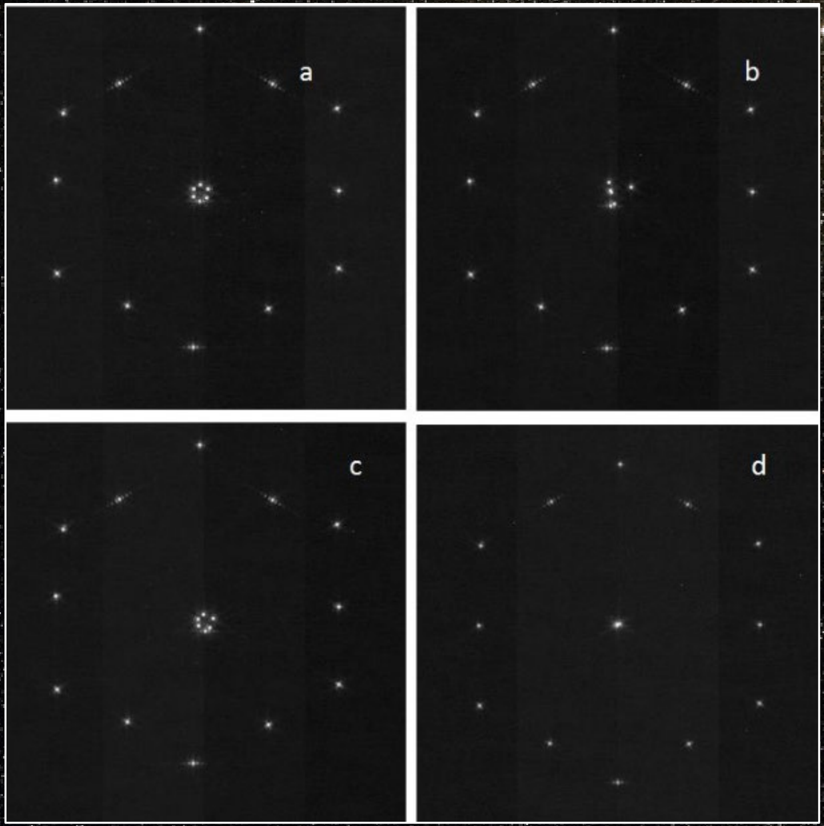
Figure 3. Segment images arranged in a hexagonal pattern for coarse alignment. Defocus is introduced by changing the despace term of the SM.

Images evaluated to determine & correct SM alignment and some PMSA alignments.

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.823.4123&rep=rep1&type=pdf

Optical, Infrared, and Millimeter Space Telescopes, edited by John C. Mather, Proceedings of SPIE Vol. 5487 (SPIE, Bellingham, WA, 2004)

Simulated Image Stacking



Mirror Alignment Video
(Note Image Stacking)

Coarse Phasing Simulation

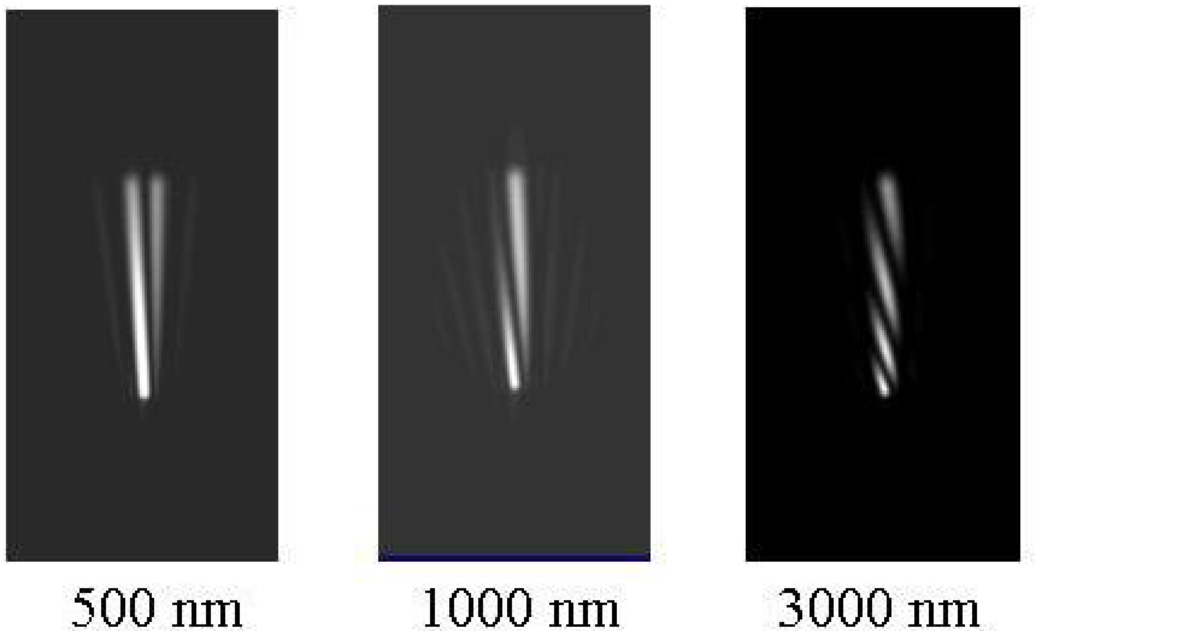


Figure 5. Dispersed fringes indicating a piston error between 2 segments.

The Coarse Phasing operations will be based on Dispersive Fringe Sensing (DFS) techniques. A dispersive element (a diffraction grating plus a prism) is placed at an image of the JWST PM within NIRCam. A pair of segments will produce a characteristic image that resembles a "barber-pole" as shown in Fig. 5. The angle and spacing of the fringes uniquely determines the pistons error between the pair of segments.

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.823.4123&rep=rep1&type=pdf

Optical, Infrared, and Millimeter Space Telescopes, edited by John C. Mather,
Proceedings of SPIE Vol. 5487 (SPIE, Bellingham, WA, 2004)

Fine Phasing Simulation

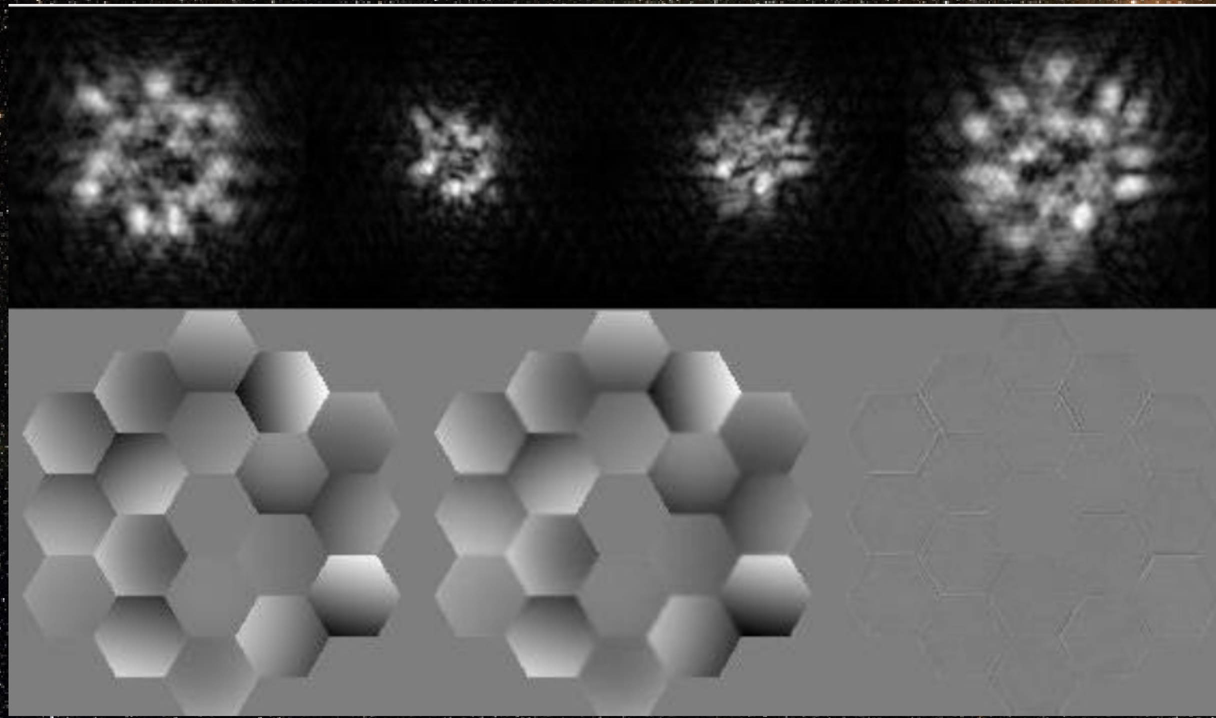
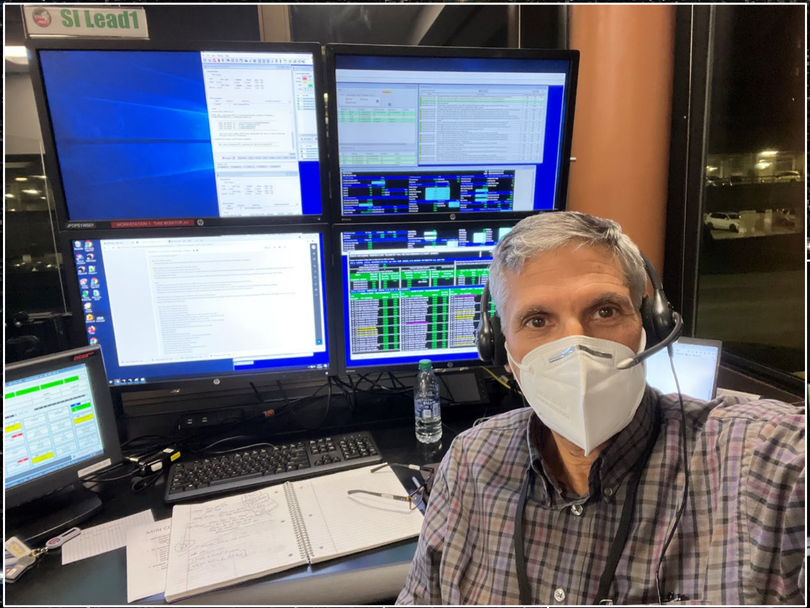


Figure 7. Fine phasing example. Top: simulated images with defocus values of –6, -3, 3, 6 waves PTV (log display). Lower left: the actual phase map (~250 nm rms). Lower center: estimated phase. Lower right: difference (~10 nm rms).

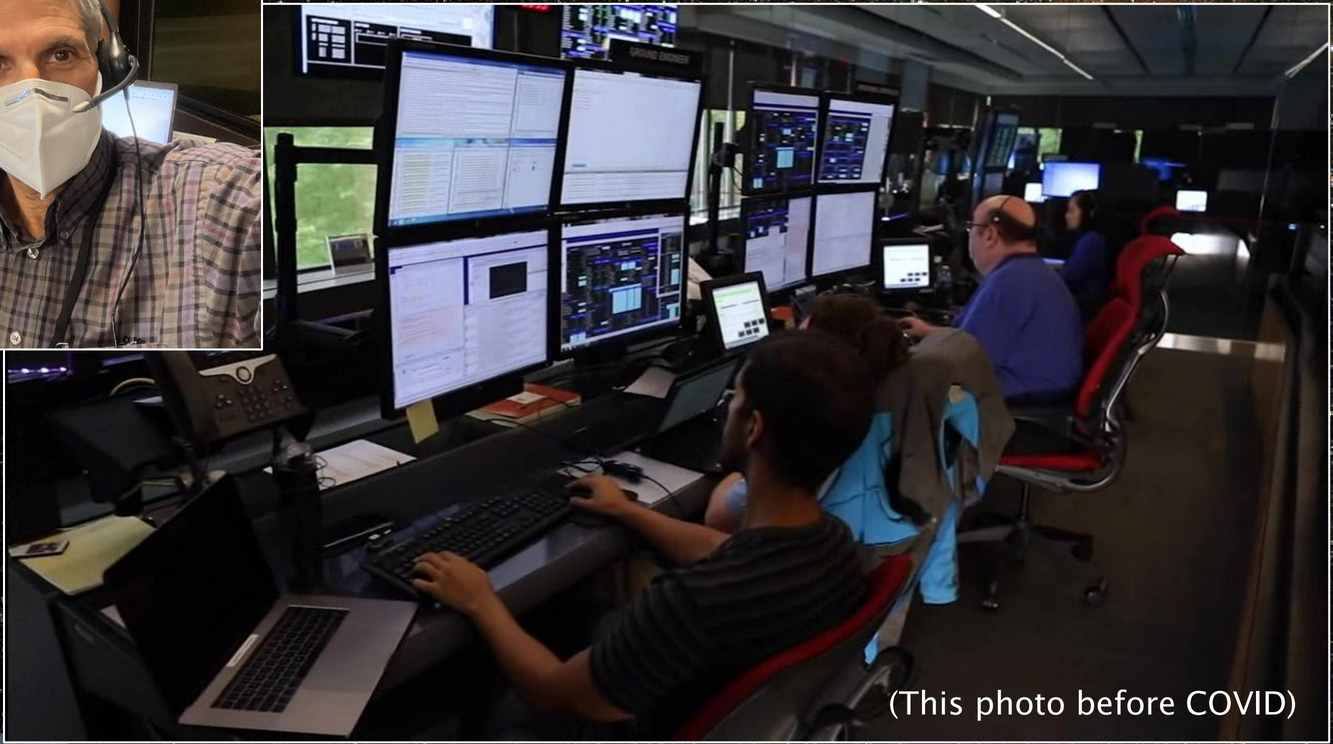
https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.823.4123&rep=rep1&type=pdf

Optical, Infrared, and Millimeter Space Telescopes, edited by John C. Mather,
Proceedings of SPIE Vol. 5487 (SPIE, Bellingham, WA, 2004)

Where I'm working now

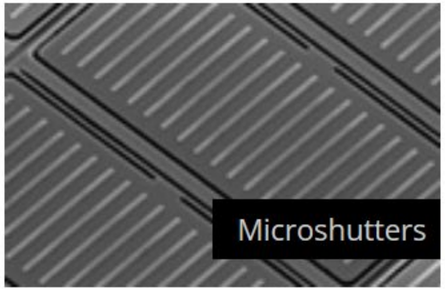


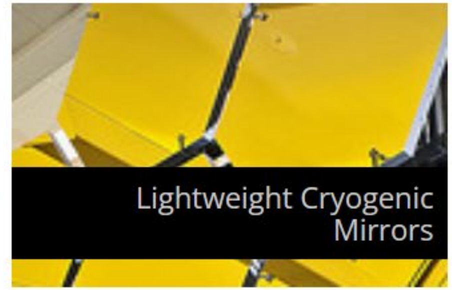
Space Telescope Science Institute (STScI)
Johns Hopkins University Campus
Baltimore, MD

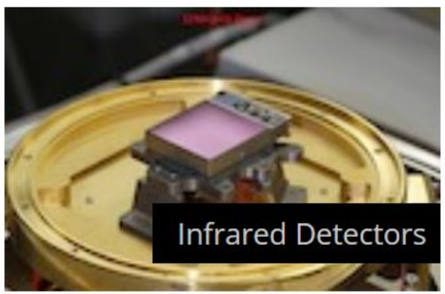


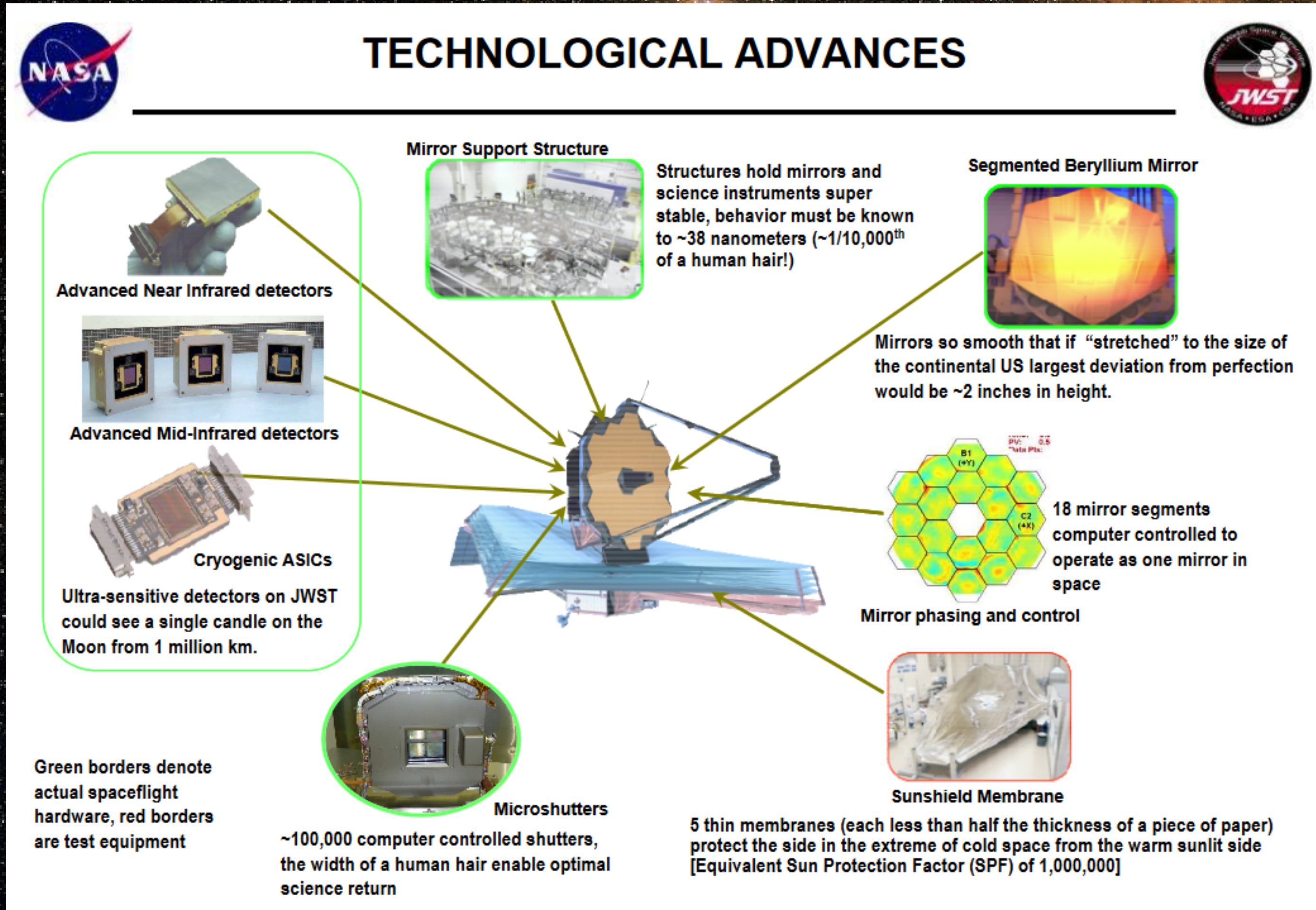
(This photo before COVID)

New Technologies Developed for Webb









https://www.nasa.gov/pdf/629955main_RHoward_JWST_3_6_12.pdf

Mirrors

- Segmented Primary Mirror / Hexagons
- Folding / Deployable
- Beryllium – polishing, good at cryo
- Cryo Actuators – 12.5mm range, 10 nm resolution (1/10,000